FUZZY DYNAMIC HYBRID MCDM METHOD FOR SUPPLIER EVALUATION AND SELECTION

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ABSTRACT

In Supply Chain Management (SCM), it is important to have good purchasing strategies to ensure optimal cost and quality of product. Supplier management is part of decision making (DM) in the purchasing process. Supplier management involves the evaluation and selection of suppliers. An accurate evaluation of suppliers can reduce the costs and improve the quality. Supplier management is complex due to multiple criteria, dynamic environment and uncertainty. Various studies have applied Multi Criteria Decision Making (MCDM) models to solve supplier management problem. However, current supplier management methods have limitations in specific situations. They do not consider the environment changes that can affect the process of evaluation and ranking.

Various intelligent MCDM methods are analyzed to find suitable methods to address supplier selection problems. The DM environment with four elements (Re-ranking, homogeny, Inconsistency, population) is defined. A Fuzzy Dynamic Hybrid MCDM (FDHM) method is proposed and developed for the evaluation, ranking and selection of suppliers. The method employs Fuzzy Analytic Hierarchy Process (FAHP) for weighting of criteria. A Fuzzy Inference System (FIS) is developed to determine the impact of FAHP method and Fuzzy Technique Of Preferences Similarity to Ideal Solution (FTOPSIS). The method for evaluation of suppliers is based on impact factors.

Experiments for supplier management in Mobarakeh steel company are carried out for different DM environments. FDHM method is evaluated by the satisfactorily and efficiency factors. The ability of methods to produce a ranking in high correlation coefficient with experts' judgment, implies that the experts are satisfied with the performance of FDHM. In each experiment, the efficiency of FDHM with other fuzzy hybrid SES decision making methods in terms of accuracy and complexity is compared. The accuracy is the first priority to determine the efficiency of FDHM in supplier management. The

complexity is calculated by the number of comparisons. In each experiment we calculate the complexity of methods in same conditions. The result shows that FDHM satisfies the expectation of the experts.

ABSTRAKT

Strategi pembelian yang baik adalah satu perkara yang sangat penting di dalam pengurusan rantaian bekalan, bagi menjamin kos dan kualiti hasilan adalah optimum. Pengurusan pembekal adalah sebahagian dari membuat keputusan (DM) di dalam proses pembelian. Ia melibatkan penilaian dan pemilihan pembekal. Penilaian pembekal yang tepat boleh mengurangkan kos dan meningkatkan kualiti.

Pengurusan pembekal kompleks disebabkan oleh kriteria yang banyak, persekitaran yang dinamik dan faktor ketakpastian. Berbagai kajian telah menggunakan model Pembuatan Keputusan Multi Kriteria (MCDM) untuk menyelesaikan masalah pengurusan pembekal. Namun, model pengurusan pembekal ketika ini masih tidak mempertimbangkan kekangan bagi kaedah itu di dalam keadaan tertentu. Mereka tidak mengambilkira tentang keadaan persekitaran yang memberi kesan ke atas proses penilaian dan penarafan.

Berbagai kaedah pintar MCDM dianalisis bagi mencari kaedah yang sesuai untuk menyelesaikan masalah pemilihan pembekal. Pesekitaran DM dengan empat elemen (Penarafan semula, persamaan, ketakkonsistenan, populasi) ditarifkan. Model Fuzzy Dynamic Hybrid MCDM (FDHM) diutarakan dan dibangunkan untuk penilaian, penarafan dan pemilihan pembekal. Model ini menggunakan Fuzzy Analytic Hierarchy Process (FAHP) bagi pemberatan kriteria. Kaedah Fuzzy Inference System (FIS) dibangunkan bagi menentukan impak kaeah FAHP dan Fuzzy Technique of Preferences Similarity to Ideal Solution (FTOPSIS). Kaedah penilaian pembekal diasaskan pada faktor impak.

Eksperimen ke atas pengurusan pembekal di syarikat Mobarakeh Steel dibuat untuk beberapa persekitaran DM yang berlainan. Model FDHM dinilai dengan faktor memuaskan dan kecekapan.

Kebolehan model itu menghasilkan koefisien korelasi yang tinggi bagi penarafan dengan apa yang diinginkan oleh pakar, menunjukkan bahawa pakar berpuashati dengan pencapaian FDHM. Bagi setiap eksperimen, kecekapan FDHM dibandingkan dengan dua model SES yang lain, dari segi ketepatannya dan kekompleksan. Ketepatan adalah yang utama bagi menentukan kecekapan FDHM di dalam pengurusan pembekal. Kekompleksan dihitung dari bilangan pembandingan. Bagi setiap eksperimen, kami menghitung kekompleksan model bagi keadaan yang sama. Keputusan menunjukkan FDHM memenuhi jakaan pakar.

Dedicated to my martyred father

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LIST OF SYMBOLS AND ACRONYMS

AI	Artificial Intelligence.
AHP	Analytic Hierarchy Process.
AIBM	Artificial-Intelligence Based Models.
ANN	Artificial Neural Network.
CBR	Case Base Reasoning.
DM	Decision Making.
DSS	Decision Support System.
EA	Evolutionary Algorithm.
ES	Expert System.
FAHP	Fuzzy Analytic Hierarchy Process.
FAHPI	Fuzzy AHP Impact.
FBM	Fuzzy Based Models.
FDHM	Fuzzy Dynamic Hybrid MCDM Model.
FFAHP	Fully FAHP.
FHM	Fuzzy Hybrid Model.
FIS	Fuzzy Inference System.
FMADM	Fuzzy Multi Attribute Decision Making.
FMCDM	Fuzzy Multi Criteria Decision Making.
FMODM	Fuzzy Multi Objective Decision Making.
FTOPSIS	Fuzzy TOPSIS.
FTOPSISI	FTOPSIS Impact.
GA	Genetic Algorithm.
LP	Linear Programming.
MADM	Multi Attribute Decision Making.
FTOPSISI	FTOPSIS Impact.
MCDM	Multi Criteria Decision Making.
MF	Membership function.
MIP	Mix Integer Programming.
MODM	Multi Objective Decision Making Impact.
MOP	Multi Objective Programming.
MP	Mathematical Programming.
MSC	Mobarakeh Steel Company.
NLP	Non Linear Programming.
SCM	Supply Chain Management.
SES	Supplier Evaluation and Selection.
SM	Statistical Models.
LWM	Linear Weighting Models.
TC	Time Complexity.
TCO	Total Cost of Ownership.
TOPSIS	Technique Of Preferences Similarity to Ideal Solution
CPQ	Ct_js_rgml* P_ligle _lb Qcjcargml
AA	Amppcj_rgml Amcddgagclr
RDL	Rpg_lesj_p Dsxxw Lsk`cp
RNDL	Rp_ncxmgb_j Dsxxw Lsk`cp

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

Today, companies concentrate on their entire supply chain to achieve effective business. The Supply Chain Management (SCM) consists of a lot of factors and strategies. The purchasing process is a key factor of SCM and, supplier management is an important task in purchasing process. Supplier management is an important and complex issue in industrial engineering to develop new products.

Supplier management is the process of evaluation and selection of suppliers (Kahraman, Cebeci, & Ulukan, 2003; Spekman, 1988). So, it is denoted as Supplier evaluation and Selection (SES). Suppliers may prepare supplements, component parts,spare parts or services which their quality and cost effects on the final product. Accordingly, an optimized Supplier Evaluation and Selection (SES) directly reduces the costs and improves the quality.

In this chapter, we give the schematic of research to make it clear and transparent.

1.1 Research Motivation

Using Decision Support Systems (DSS) for supplier management in companies has a great influence to prevent the frauds, increase Profits and establish justice. However, the managers do not trust to use DSS in sensitive cases. This is caused by their decision methods weaknesses. Attracting the full confidence of managers to use DSSs in supplier selection has motivated us to select supplier management as the focus of interest in this study.

The secondary reasons for doing this research are:

i) *To produce an accurate supplier evaluation*: An intense competition in global markets has encouraged companies to focus omit on their entire supply chain. Among activities related to supply chain management, purchasing is more strategic because the cost and quality of purchasing items have a direct and significant influence on end products. Therefore, an accurate supplier management is a major contributor in manufacturing high quality products at a low price.

ii) *To extend the current research in Multi-criteria evaluation and selection*: Current methods for Multi-Criteria evaluation and selection do not consider environment changes. These methods apply the same strategies for all requested evaluations. Hence, It is important to propose a global Decision Making (DM) method to consider different environments.

1.2 Problem Statement

Supplier selection is a crucial decision making process, since efficient SES has a high influence on customer satisfaction. Multiple critical factors such as: price, quality, on time delivery, technical ability and warranty should be considered in SES to produce a comprehensive evaluation. Thus, SES is complicated by multiple criteria hence is considered as Multi Criteria Decision Making (MCDM).

Supplier selection is also complicated by the environment changes that may reduce the accuracy of employed decision methods. Furthermore, the input information regarding environment, importance of criteria and the ability of suppliers in each criteria is based on experts' opinions. The experts express their opinion as linguistic variables which are uncertain.

Fuzzy AHP and TOPSIS methods have very strong relation with applying in supplier managements. However, these methods do not consider to the environment changes. Fuzzy AHP has limitations in situations with high probability of re-ranking, inconsistency and high population. Fuzzy TOPSIS has limitations in situations with specialist alternatives.Therefore, we consider supplier selection as an uncertain dynamic MCDM problem.

1.3 Aim and Objectives

The study aim to find a method to evaluate and select suppliers with high efficiency. We intend to achieve the following research objectives:

- To identify the decision making methods applicable to supplier evaluation and selection;
- To analyze the performance of identified methods;
- To develop a new decision making method to overcome the limitations of identified methods;
- To evaluate the performance of the method.

1.4 Research Questions

The study attempts to answer the following questions corresponding to the objectives identified in the above section.

Objective 1: To identify the decision making methods applicable to supplier evaluation and selection.

- What are the supplier evaluation and selection methods?
- What are the AI and MCDM methods that are applicable to SES?
- Which one is the best technique for SES?
- How can this technique be applied to SES?

Objective 2: To investigate the performance of identified methods.

- What is the decision environment?
- How is the performance of identified MCDM methods in different decision making situations?

Objective 3: To develop a new evaluation method.

- What are the necessary criteria to overcome the limitations.
- What are the methods that fit these requirements?

Objective 4: To evaluate the performance of the method.

- How can the performance of the proposed method can be evaluated?

1.5 Research Process

The Process of this research has five steps based on our research objectives and questions (Fig. 1.1).

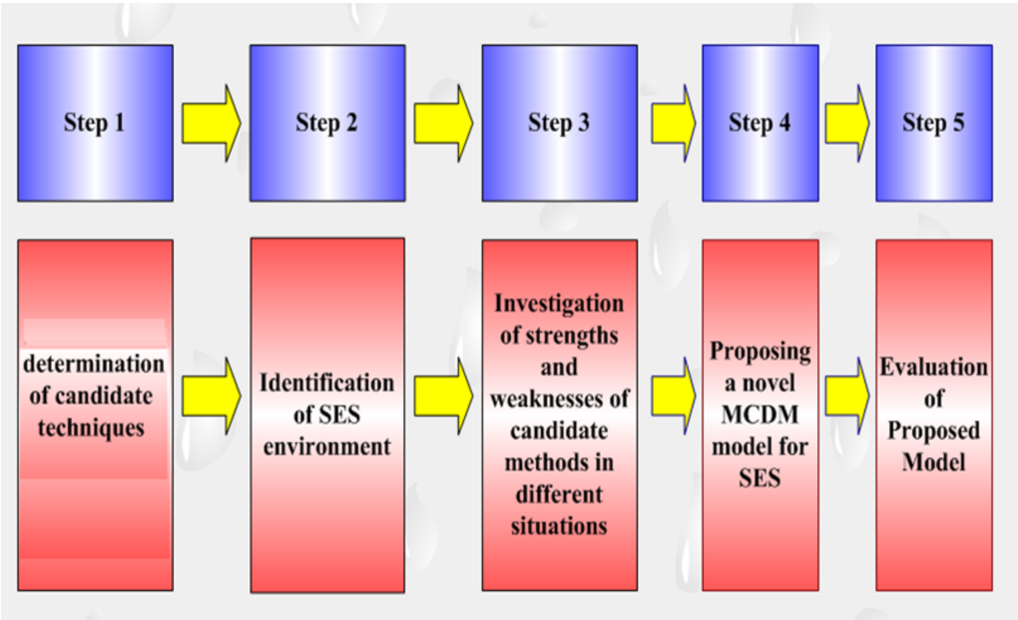


Figure 1.1: Research process

- **Step 1: Determination of candidate techniques**

We review the supplier management literature to find the applicable AI and MCDM methods for SES. The related articles are collected from Web of Science data base. The statistical analysis on applied techniques and operations in related articles is conducted. The results of analysis determine the best AI and MCDM methods for SES.

Also,we Analyze the literature of applying AI techniques in MCDMs to find the methods of applying different AI techniques in MCDMs. We classify the types of applying each AI techniques in MCDMs. Our factors to determine the suitable way of applying candidate methods are i) *relation between method and operations* and ii) *relation between operations and DM requirement*. As a result, we determined fuzzy based methods as the best suited method for the SES.

- **step 2: Identification of SES environment**

  In this step we identify the changeable and dynamic situations of decision making in supplier evaluation and selection. This situations are defined as SES environment. The dynamic situations are determined as: probability of re-ranking in SES, Probability of inconsistency, population of criteria and alternatives and homogeny of alternatives. In literature, we collect the existing analysis of fuzzy AHP and fuzzy TOPSIS methods in few mentioned situations.

- **Step 3: Investigation of strengths and weaknesses of candidate methods in different situations**

  We analyze the performance of FAHP and FTOPSIS in different situations. in each situation we use a sample experiment to analyze both methods. For example in homogeny situation, the sample experiment involves three criteria with the same weights and three specialist alternatives. In this experiment we see the limitation of FTOPSIS in ranking specialist alternatives. For analyzing methods in population situation, an experiment is conducted to calculate the number of needed comparisons in FAHP and FTOPSIS methods.

- **Step 4: Developing a novel Fuzzy Dynamic Hybrid MCDM method for SES** .

  The necessary criteria to overcome the limitations of current methods are investigated. We develop the FDHM method based on three strategies: *(i) dynamization*, *(ii) methods integration* and *(iii) DM fuzzification*. In *dynamization*, we develop a Fuzzy Inference System (FIS) to evaluate the appropriateness of identified methods based on decision environment. The FIS determines the impact of identified methods based on situation of alternatives, criteria and decision makers.

  For the *methods integration*, we hybridize the identified methods to get benefit from their strengths and to overcome their limitations in different situations of environment.

  For *fuzzification* of decision making, we employ fuzzy set theory (Zadeh, 1965) to handle vagueness and subjectivity of linguistic variables which are produced by decision makers in assessing criteria, alternatives and decision making situations. On the other hand, the FIS is developed based on fuzzy Membership function (MF)s and fuzzy "if-then" rules. In FIS, for each situation the appropriate MF is considered based on the aspects involved in the considered situation.

- **Step 5:** Evaluation of FDHM method.

  We carry out experiments for SES in a steel company as a case study. We examine the method in various situations of SES. Then,we measure the performance of the method in terms of accuracy and time complexity by comparing the method with other methods.

1.6 Research Scope

There are different perspectives for SES such as single/multiple criteria, single/multiple products, objectivity/subjectivity, quantitative/qualitative criteria, human judge (special consideration to decision makers' judgments) and cost (special consideration to the costs). The SES is considered as decision making with the continued environment and sometimes as decision makings with discrete environment. Looking at the SES from different perspectives requires different methods since the same method can not be applicable for different SES. The supplier management is an extended area with different considerations. In this research we consider the popular SES which exists in industrial companies. Table 1.1 shows the considerations of this research for supplier management.

Table 1.1: Considerations of research for SES

SES considerations	Addressing in this research
multiple criteria	$\surd$
multiple products	$\times$
subjectivity	$\surd$
human judge	$\surd$
cost	$\times$
continuous environment	$\times$
discrete environment	$\surd$

The industrial companies have different methodologies, facilities and abilities to gather information about their suppliers. Often, they do not have much information about suppliers or they do not trust them. In such a situation, the methods for the SES will differ to those with detailed and precise information regarding suppliers. In major industrial companies such as steel companies, the information has a medium level of inconsistency and we do not consider them as gray information. Therefore, in this study we do not look at the gray theory which is suitable for high level of inconsistency.

1.7 Significance of Study

Managers are constantly making decisions at different times. Often, these decisions are subject to collateral issues and policies. Also, the fatigue and carelessness of managers may lead to a wrong decision. This problem has led to the development of decision methods.

Although, these methods have shown a great potential. However, according to the vote of more than 100 managers from different companies in 2009, these methods have not yet gained the full confidence of managers. The distrust and dissatisfaction of mangers in using DSSs is caused by the low level of accuracy (Gudigantala, Song, & Jones, 2011). The increase of this confidence is very precious to strengthen management. This research attracts the full confidence of managers to use DSSs in supplier management by proposing a DM method with high satisfaction degree of experts. The satisfaction degree of proposed method is measured in chapter 5.

Proposing an accurate SES method directly reduces the costs and improves the quality of products. This is economically very beneficial for companies.

The MCDM methods have a wide range of applications in manufacturing, economy, supplier management, industries, project/service management, environmental management, human resource management, risk management, medical, military and etc. Therefore, proposing an efficient DM method can effect on the process of decision making in the above mentioned issues.

1.8 Thesis Layout

This thesis is a research work on supplier management and intelligent MCDM techniques (AI based MCDM techniques), particularly on how we developed a MCDM method for evaluation and ranking of suppliers. In this chapter we explain our reasons to conduct this research, the problems of supplier selection, objectives of this research and relevant research questions. This is followed by a brief discussion on research methodology and importance of an effective MCDM method for supplier selection.

The second chapter reviews the literature of supplier management. This chapter is divided into two parts:

- In the first part (supplier management strategy), we review the place of SES in SCM, SES components, SES process and methods.

- In the second part (supply management methods), we discuss the different perspectives on SES and their related applicable methods, in particular, MCDM and Artificial Intelligence (AI) based methods. Therefore, we review and analyze the methods of applying AI techniques in MCDMs as well as AHP and TOPSIS methods and their limitation in addressing uncertainty.

Chapter 3 divides to two parts:

- In the first part we analyze the methods, operations and applications of AI/MCDM based papers to find the required operations for SES, determine the most suitable AI and MCDM methods which can fulfill the SES requirements. We find the best type of hybridization for the identified MCDM and AI methods. We determine the Fuzzy AHP and TOPSIS methods as candidate methods for SES.

- In the second part, We then define the environment of decision making. Then we analyze the manner of fuzzy AHP and TOPSIS method in changing the elements of the environment. We find their strengths and limitations in these situations. The problems of these methods for supplier management are expressed in this section.

The problems in SES are identified in chapter 2 and 3. A part of problem regarding the uncertainty is explained in chapter 2 and another part which is related to changing environment and limitations of methods is in chapter 3 (Fig. 1.2).

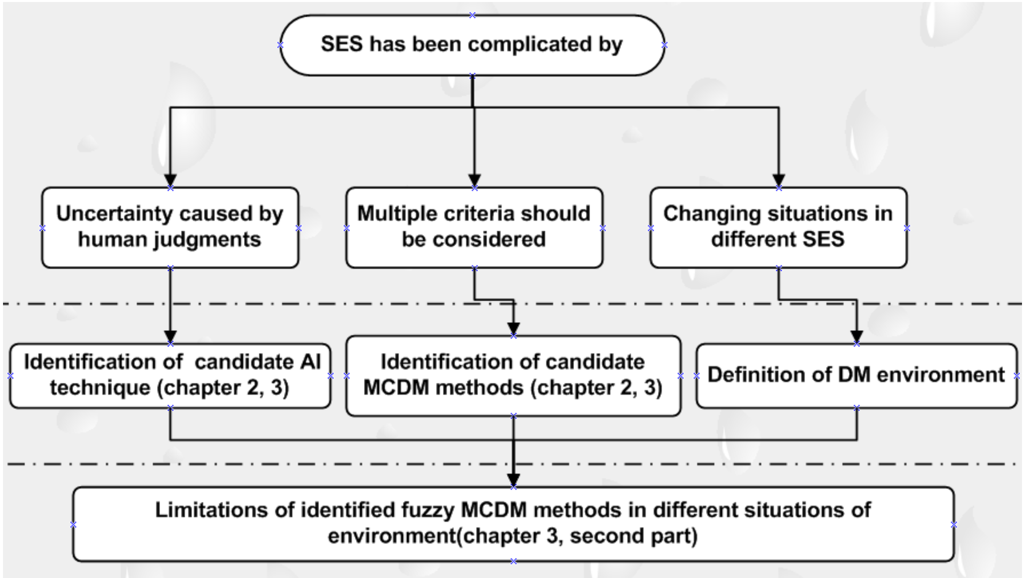


Figure 1.2: Distribution of research problem in chapter 2 and 3

Chapter 4 describes the development of the proposed method. This method is designed to overcome the problems of Analytic Hierarchy Process (AHP) and Technique Of Preferences Similarity to Ideal Solution (TOPSIS) methods identified in chapter 2 and 3.

Chapter 5 is about the evaluation of the method. Finally we conclude our research in chapter 6. In this chapter we describe the findings of our research and explain the limitations of the work and provide suggestions for future work that can be carried for this research.

CHAPTER 2

SUPPLIER MANAGEMENT

2.1 Introduction

Supplier management, as a key factor in Supply Chain Management (SCM), greatly influences the performance of companies (Carr & Smeltzer, 1999). Supplier management requires the evaluation of suppliers and the selection of best suppliers. So, in this work we use the term "Supplier Evaluation and Selection(SES)" to refer to supplier management. Managers of companies focus on SES as a success factor in their respective business (Ellram & Carr, 1994). In a traditional SES, price forms the main competition factor between the suppliers, which renders certain important qualities, such as quality of product, level of trust, commitment, and expertise unobtainable (Spekman, 1988). The ever increasing number of these factors propelled the MCDM methods to the forefront of this field more than ever before. In this quest, multiple models and methods have been proposed and applied for the evaluation and selection of suppliers.

This chapter is divided into two sections. The first section (supplier management strategy) reviews the place of SES in SCM, SES components, SES process, and models, while the second section (supplier management methods) reviews and analyse several methods including the MCDM methods and the combination of AI techniques and MCDM methods.

2.2 Supplier management strategy

Supply Chain Management (SCM) is the active management of supply chain components that maximizes customer satisfaction and realizes a sustainable competitive advantage. It represents a conscious effort by the supply chain firms to develop and run a supply chain in the most effective and efficient manner (Croxton, Garcia-Dastugue, Lambert, & Rogers, 2001).

A basic SCM involves five components; planning, sources management, manufacturing, delivery management, and return management (Croxton et al., 2001) , all of which respond to different duties in the context of managing a supply chain. Fig 2.1 shows the general process and the main components of a supply chain management.

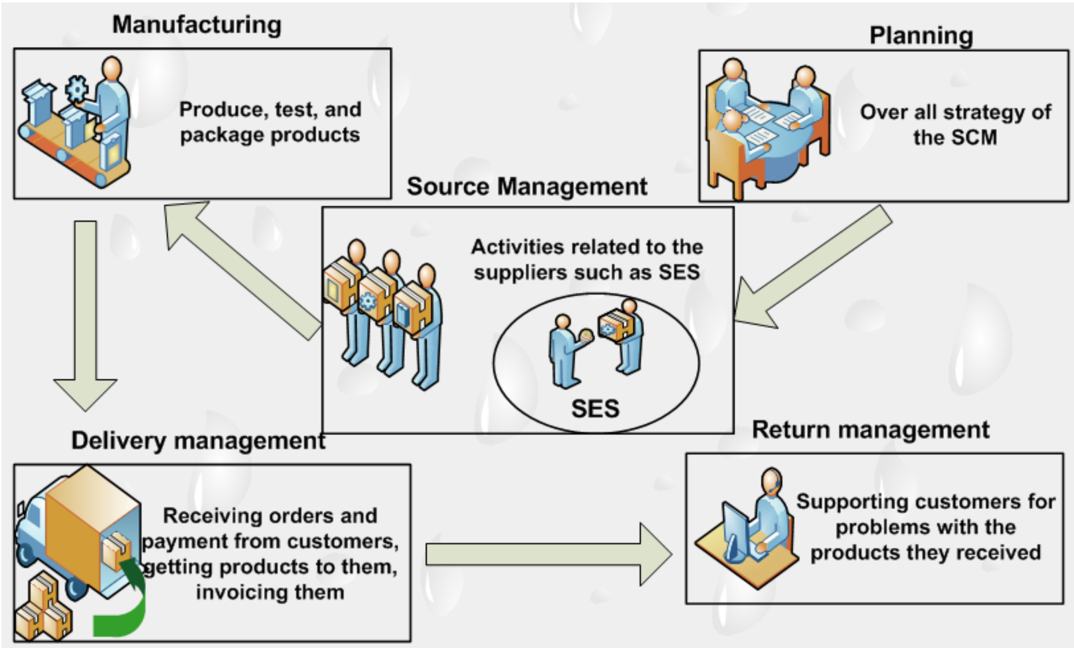


Figure 2.1: SCM Process and Components

Source management concerns the activities related to the suppliers who provide the required goods and services to run a business. Supplier management is a key procurement decision in source management. Suppliers have high influence in procuring products or services, either directly in their own business activities, or through other suppliers along their respective supply chain. Therefore, selecting the right suppliers for a contract is a critical juncture in the purchasing process of source management. Accordingly, managers need to evaluate a range of suppliers to determine which has the highest likelihood of meeting their respective needs. These suppliers are then invited to bid for the contract.(Croxton et al., 2001)

2.2.1 SES Components

Supplier evaluation and selection is a decision-making process. In this process, the decision makers evaluate and select the best supplier according to the directly or indirectly determined criteria. This evaluation is very complex, especially when there are various suppliers and criteria. In such cases, decision-makers are assisted by Decision Support Systems (DSSs) when it comes to selection of suppliers (De Boer, Labro, & Morlacchi, 2001).

Decision-makers and DSS receive needed information from the suppliers. Decision makers determine the criteria and send their judgement regarding the saliency of suppliers in the criteria to the DSS (Rushton, Croucher, & Baker, 2014). The DSSs then function based on decision-making methods and recommend the best suppliers to the decision-makers (Fig 2.2). Therefore, the criteria involving decision, suppliers, and decision makers are imperative to decision-making. These components fluctuate as per different decisions, so if a decision making model or DSS are dependent on these components, then it will only be usable for a short period of time or application.

i) Criteria: The criteria are some critical factors that are considered decision-making, which assists decision-makers in making choices. In previous models, managers will only take into account certain criteria, such as the common price and delivery methods (Ellram, 1990; Scott and Westbrook, 1991). However, their considerations changes when trying to decide on a supplier, as criteria and factors fluctuate in accordance to the competitive nature of the markets. This causes that the decision-makers be more selective when evaluating suppliers, as factors such as low quality goods and poor delivery system might result in a more costly product (Bevilacqua & Petroni, 2002). A new strategic approach to purchasing includes introducing new sets of criteria for supplier selection. These criteria can either be well-defined and quanti-

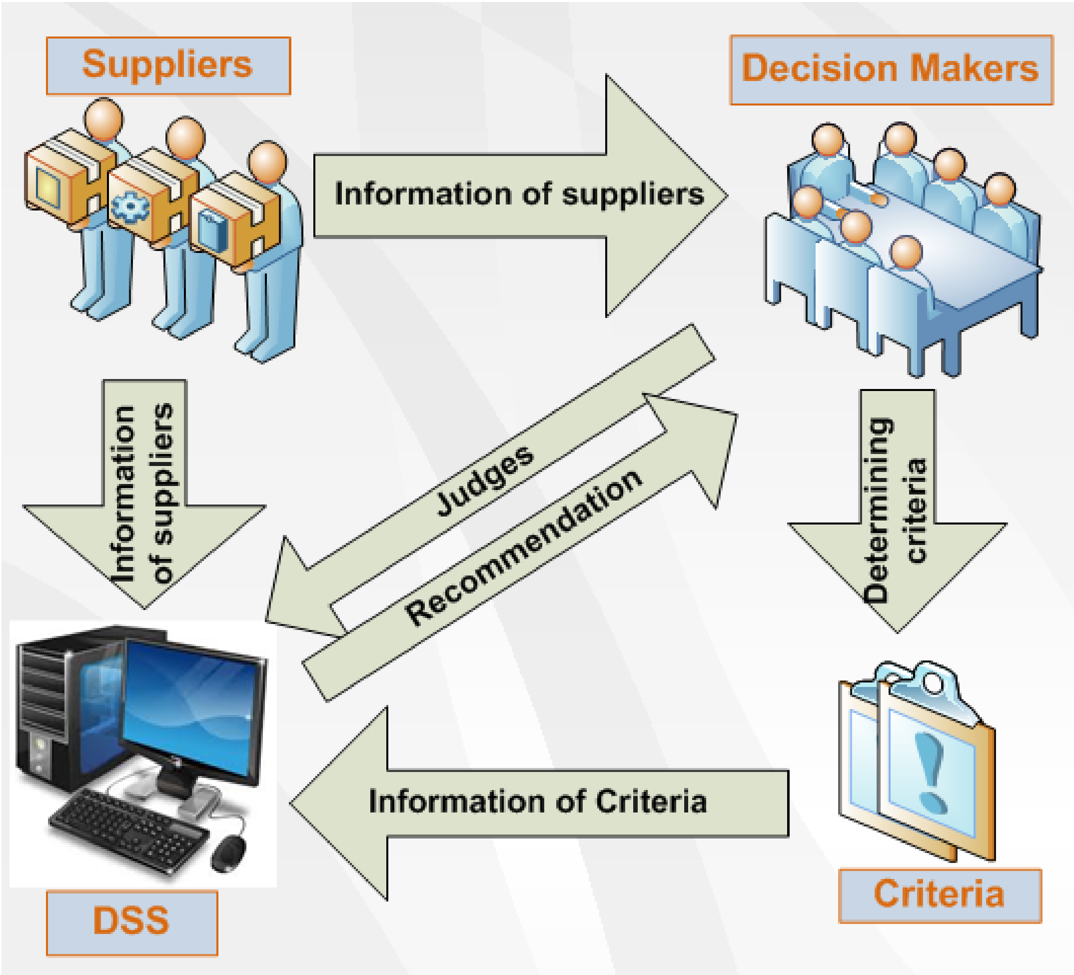


Figure 2.2: Interaction between SES components

tatively measurable, such as price, financial capability, and investment capacity, or they can be qualitative and difficult to measure, such as flexibility in the production line, expertise of experts, quality, maintenance, and high technology.

Each company may have different requirements depending on the industry and items that are to be purchased. Therefore, the set of criteria for supplier selection constantly fluctuates, and the proper set of criteria that differs is the SES.

ii) Suppliers: The purchasing division of industrial companies, such as steel companies, procure multiple materials, services, and products. The type and number of suppliers in this procurement differs based on type of purchased items.

For instance, the Mobarake Steel Company (MSC) has only one supplier for their electricity, while it has multiple suppliers for office appliances. The suppliers of office appliances are very similar to each other, with no defining characteristics among themselves. Accordingly, any decision-making model or system should be able to address the different types of suppliers in SES.

iii) Decision Makers: In SES, decision makers include managers, experts, and generally those who evaluate and select the suppliers. The number of decision makers in decision-makings differs, they might be made up of a team, or work alone. When there is a team of decision makers, then their opinions should be normalized and averaged (Sanayei et al., 2010).

Supplier selection in industrial companies is a difficult and complicated decision-making process. This prompts the decision makers to employ DSS for quick recommendations, which will allow them to streamline their choices. However, the decision-makers still remain crucial to the decision making process, and remains irreplaceable by DSS or other decision models, and as a matter of fact, these models (DM models) are mostly based on the opinions of decision makers.

There are two types of DSSs; static and dynamic. The classification is made based on their respective behaviours. In static DSS, the embedded decision making methods in DSS remained unchanged when multifarious decision cases into the system are entered (Brans and Mareschal, 1994; Bui and Lee, 1999; Turban, 1990).

The current version of DSS is related to standard SES, and they do not take into account the changing decision components in several SESs (De Boer, Labro, & Morlacchi, 2001; Ho, Xu, and Dey, 2010). However, in a dynamic DSS, the decision methods are influenced by environmental changes, and those being selected will be moulded based on these respective changes. The accuracy of these systems is high, since they make the optimum decision in accordance to multiple situations (Lai & Li, 1999; Chang, Hong, and Lee, 2008; Katok, Lathrop, Tarantino, & Xu, 2001).

2.2.2 SES Process

There are many companies that make various purchases from multiple suppliers. Despite this generality and multiple facets, the process can be generalized into a few distinct steps (Fig 2.3).

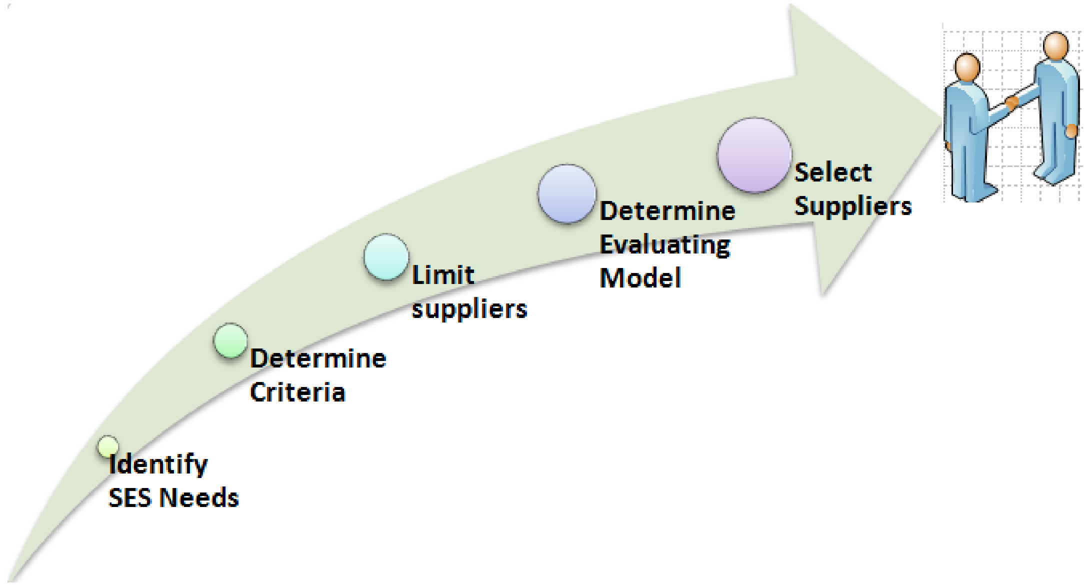


Figure 2.3: Interaction between SES components

Step 1: Identifying the need for SES. This step usually implies the identification of the need for a special product or service. Different situations might change the need for supplier selection. For example, the primary information regarding suppliers are specific to every company and interaction, and can be obtained from the suppliers themselves, or previous suppliers who are privy to this information(s).

Step 2: Determination of Criteria. SES is complicated due to the multiple criteria involved in the decision-making process. Various studies have prepared a set of criteria for SES (Dickson, 1966; Weber et al., 1991; Bharadwaj, 2004). Dickson (1966) proposed the first list of criteria for SES and determined the importance of related criteria (Fig. 2.4). However, these criteria are not applicable to all companies, or for all materials and services supplied by suppliers. For example, cost is frequently mentioned as an important criterion. However, when the service is similarly priced across all suppliers, for example the price of steel, then cost cannot be used as a criterion.

Rank	Factor	Mean rating	Evaluation
1	Quality	3.508	Extreme importance
2	Delivery	3.417	
3	Performance history	2.998	
4	Warranties and claim policies	2.849	
5	Production facilities and capacity	2.775	Considerable importance
6	Price	2.758	
7	Technical capability	2.545	
8	Financial Position	2.514	
9	Procedural compliance	2.488	
10	Communication system	2.426	
11	Reputation and position in industry	2.412	
12	Desire for business	2.256	
13	Management and organization	2.216	
14	Operating Controls	2.211	
15	Repair Service	2.187	Average importance
16	Attitude	2.120	
17	Impression	2.054	
18	Packaging Ability	2.009	
19	Labor relations record	2.003	
20	Geographical location	1.872	
21	Amount of past business	1.597	
22	Training aids	1.537	
23	Reciprocal arrangements	0.610	Slight importance

Figure 2.4: The criteria of supplier selection and their importance (Dickson, 1966)

Swift (1995) has proposed a set of classified criteria. When the comparison of criteria is used for calculation of their weights. This classification helps to experts in immediate recognition of criteria and better comparison of criteria (Fig. 2.5).

Step 3: Limit Suppliers in Selection Pool. Companies need limited resources. Therefore, a purchaser needs to pre-screen the potential suppliers before conducting a more detailed analysis and evaluation. The supplier selection criteria determined in Step 2 plays a key role in this reduction process.

Companies have different policies in this step, such as limiting suppliers that satisfy certain "entry qualifier" before proceeding to further analysis (Christopher & Peck, 2004). This step is applicable to SES, with a huge number of suppliers, as well as a precise and important criterion, separate from the other criteria.

Product
- Ease of operation
- Ease of maintenance design
- Impact on energy utilization
- Amount of prepurchase information
- Contribution to productivity
- Cost of service contract

Availability
- Breadth of product line
- Geographic proximity
- Vendor's image
- Supplier's financial condition
- Warranties

Dependability
- Ability to keep delivery promise
- Technical support available
- Reliability of product
- Service response time

Experience
- Preferences established by users
- Prior experience with vendors
- Reputation of suppliers

Price
- Price/performance
- Low price
- Total cost of product

Figure 2.5: The classified list of criteria for SES (Swift, 1995)

Step 4: Determination of Evaluating Model. There is a wide range of SES models, as will be discussed in section 1.1.4. Despite the wide array of models, it cannot be ascertain for sure which models are superior, as the classification depends on the intended applications. In order to determine whether a model is suitable for our purposes, it should be based on the results of the first and second steps (Bufardi, Gheorghe, Kiritsis, & Xirouchakis, 2004; Dagdeviren, Yavuz, & Kilinc, 2009; Mergias, Moustakas, Papadopoulos, & Loizidou, 2007).

Step 5: Select Suppliers and Reach Agreement. The final step of SES is to clearly select suppliers who meet the company's sourcing strategy in a suitable manner. This decision is often accompanied with the determination of the order quantity allocation to selected suppliers.

2.2.3 SES Models

There are many different perspectives for SES, such as single/multiple criteria, single/multiple products, objectivity/subjectivity, quantitative/qualitative criteria, human judge (special consideration to decision makers' judgments) and cost (special consideration to the costs).

Moreover, SES is sometimes regarded as a decision-making process with the continued environment, and other times as a decision-making process with discrete environment. Looking at SES from different perspective might make it applicable for multiple models. Generally, the researchers divide the SES models into five groups; Linear Weighting Models (LWMs), Total Cost of Ownership (TCO), Statistical Models (SMs), Mathematical Programming (MP) and Artificial Intelligence Based Models (AIBMs) (Abraham, Jain, Thomas, & Han, 2007; Chai, Liu, & Ngai, 2013; de Boer, et al., 2001). In this work, we extended this classification to six groups by adding "hybrid models" as shown in Fig.2.6. In the following section, we explain the SES models being considered in this work.

i) Linear Weighting Models (LWMs): These models calculate a numerical weight on each selection criterion, and then determine a total score for each supplier by summing up the supplier's performance on the criteria multiplied by these weights. Although these approaches are very simple, they heavily depend on human judgment and proper scaling of criteria values. Some of the Multi Criteria Decision Making (MCDM) methods such as Analytic Hierarchy Process (AHP), ANP (Analytic Network Pro-

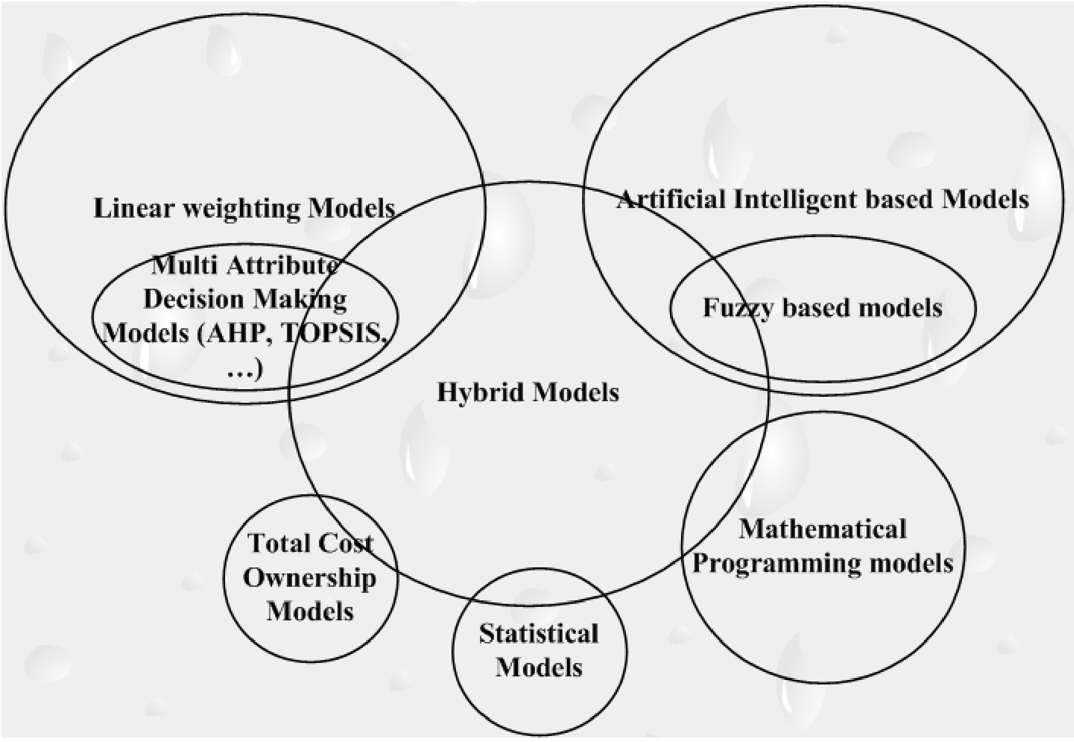


Figure 2.6: SES models

cess), and TOPSIS are classified as LWM. These models are more accurate than other SES models in terms of multiple criteria evaluations (Abraham, et al., 2007).

ii) Total Cost of Ownership models (TCO): These models took into account all of the direct and indirect costs in the supplier choice that arises during the item procurement life cycle. The TCO determine the exact cost of a purchase from a supplier, and includes all main costs related to a particular purchase. The important costs, which should be involved in TCO, are the pre-transaction costs (from request to order placement), transaction costs (from order placement to receipt), and post-transaction flows (from receipt to access). Typically, the pre-transaction costs are related to investigating and qualifying procurements, or adding new suppliers to the company's IT system. Transaction costs include price, shipping costs, and controls, among others, while post-transaction costs include row precipitation, changes, price of returns, and guarantees working (Ellram & Perrott Siferd, 1993). These models only take into account the criterion of cost for the evaluation of suppliers.

iii) Statistical models (SMs): These models usually address the uncertainty in demand and stochastic lead times. Stochastic uncertainty exists in most types of purchasing situations, such as being unaware of exactly how the internal orders should be developed for purchasing items or services. However, only few supplier choice models really address this problem. The published statistical models can only handle the uncertainty related to one criterion at a time (de Boer, et al., 2001).

iv) Mathematical Programming models (MP): These models allow decision makers to account for the different restrictions in SES. These models can deal with situations where each supplier has multiple products. Using MP models, decision makers formulate the decision problem in terms of a mathematical objective function, due to the fact that it needs maximization in certain parameters, such as profit, or minimization in others, such as costs. For this purpose, they change the values of variables in the objective function, such as the amount ordered by a specific supplier.

MP models can optimise results using either single objective models or multiple objective models. Single objective models, such as Linear Programming (LP), Non-Linear Programming (NLP) and Mix Integer Programming (MIP) focus mainly on minimising costs or maximising profits. Multi-objective models, such as the Goal Programming and Multi-Objective Programming (MOP), deals with the problem optimisation involving two or more inconsistent criteria. MP models force decision-makers to precisely state the objective function. Therefore, they are completely objective programming, and they do not consider the subjectivity in the process of decision-making.

These models are applied for MODM. Recently, researchers integrate these models with other methods, such as fuzzy techniques in uncertain MODM (Amin, Razmi, & Zhang, 2011; Buyukozkan & Cifci, 2011; Ghorbani, Mohammad Arabzad, &

Shahin, 2013; Ozkir & Demirel, 2012; Ozkok & Tiryaki, 2011; Tajik, Azadnia, Ma'aram, & Hassan, 2014; Wang & Li, 2011; Yilmaz & Dagdeviren, 2011).

v) Artificial-Intelligence Based Models (AIBMs): They apply the AI techniques to analyse decisions (Appendix C). These models are applied in DMs based on the decision makers' judgements. They are able to emulate human decision-making process. These models can deal with the complexity and uncertainty involved in the SES process very well. Example of these models are Fuzzy Techniques (FTs), Expert System (ES), Artificial Neural Networks (ANNs), Evolutionary Algorithms (EAs) and Case Base Reasoning (CBR). Section (2.7) discusses these methods in more detail.

vi) Hybrid Models (HM): HM is the integration of the aforementioned models. There are various types of HM, such as the integration of AIBM with each other, integration of LWM with each other, integration of AIBM and LWM, integration of AIBM with TCO, and the integration of AIBM with MP. Between the multitude of methods, Fuzzy Techniques (FTs) is the one that can be most integrated with the others.

Table (2.1) shows the relation between perspectives of SES and applied models to solve this problem. Considering the type of integration in HMs, they are capable of dealing with multiple perspectives.

Table 2.1: SES perspectives and models

perspectives/Models	LWM	TCO	SM	MP	AIBM	HM
Multiple criteria	√	×	×	√	√	D[1]
Multiple products	×	×	×	√	×	D
Subjectivity	×	×	√	×	√	D
Human judge	√	×	×	√	√	D
Cost	×	√	×	×	×	D
Continuous	×	×	×	√	√	D
Discrete	√	√	√	√	√	D

According to the scope of this research (section 1.6), HM of integration of LWM and AIBM is the best option in addressing SES. The multiple criteria perspective highlights the MCDM methods among LWMs. Therefore, in the following sections, we review the literature on both MCDM and AIBM.

2.3 Supplier management methods

We limit the domain of literature to find the candidate methods for supplier selection in industrial companies. In previous section we discussed about the existing model and their abilities to deal with different aspects of supplier selection (table 2.1). According the attributes of existing model and the scope of research (section 1.6), The AIBM models and methods are selected. In next chapter we limit the domain of research to fuzzy methods and then Fuzzy AHP and TOPSIS. Figure 2.7 shows the limiting of research domain from all SES methods and models to the candidate methods (FAHP, FTOPSIS).

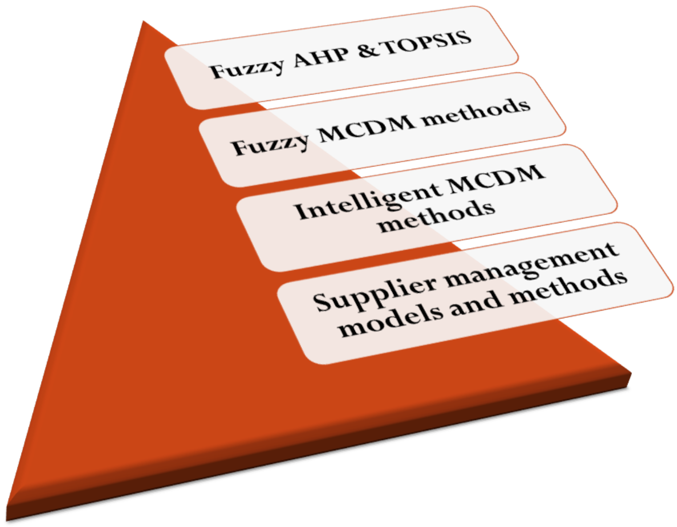


Figure 2.7: Limiting the research domain

This limiting process in based on three criteria:

i) The abilities of models and methods to overcome the different aspects of SES,

ii) The aspects of SES in industrial companies (determined in section 1.6),

iii) The relation between number of employing methods and required SES operations.

In this section, we review the supplier management methods, including MCDM methods such as AHP and TOPSIS however the critical analyzing and problem identification is explained in section 3.3. We also review the literature on the combination of AI techniques and MCDM methods to address the considered decision-makings processes.

The Fuzzy MCDM (FMCDM) method is a strong candidate method for SES to deal with the subjectivity and multiple criteria in these DMs. The citation analysis reported by Web of Science (WoS) regarding FMCDM shows the growing use of these methods by researchers around the globe (Fig 2.8).

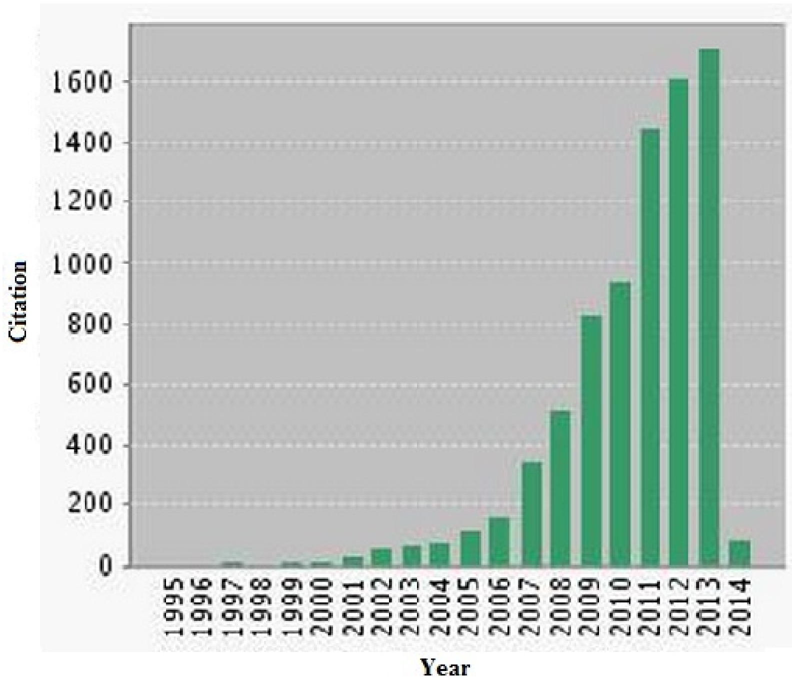


Figure 2.8: Citation report of FMCDM, from WoS at 20 Jan 2014

2.3.1 Multi-Criteria Decision Making (MCDM)

Real world DMs becomes more and more difficult; judging by what is visible in a one-dimensional way and using only a single criterion (Zelendy, 1982). Taking into account only a criterion in the decision-making process is just a simplistic approach to the nature of DM at hand. However, it might lead to unrealistic decisions.

A more appealing approach would be the simultaneous consideration of all pertinent factors related to DM, which we regarded as Multi-Criteria Decision Making (MCDM). However, the use of this approach gives way to some rather interesting questions: how can several and often inconsistent criteria be aggregated into a single evaluation model? Is this evaluation model a unique and optimal one?

Researchers from different disciplines have tried to address the first question using statistical approaches; Artificial Intelligence (AI) techniques and Operations Research (OR) methodologies. The success and utility of these efforts should be studied with respect to the second question. Obviously, a DM is not addressed in a similar manner by all decision makers. Each decision-maker has their respective settings, expertise, and DM policies. Thus, one expert's judgment is expected to vary from another (Zopounidis & Doumpos, 2013). This is a significant issue that should be taken into account during the development of DM models. The MCDM is categorized according to the aspect of types and methods.

2.3.1 (a) MCDM Types

Multi-criteria decision making is categorized into two types based on the environment and situation of decision making as MODM and MADM. They are both similar and different in certain aspects. In general, MADM can be regarded as an alternative question, and in order for us to answer this question, we need to evaluate alternatives and select the best answer. On the other hand, MODM resembles an analysis question and in order to answer it, a solution has to be found. The main purpose of MADM is to select the best alternatives, but in MODM, it is to find the solution that fulfils the objectives. It will also be pointed out in more detail later that MODM is made up of continuous variables, while MADM is made up of discrete environment. In both MADM and MODM, criteria should be determined prior to the decision making process.

i) Multi Objective Decision Makings (MODM): They are decision-making process in a continuous environment. In this type of decision making, situation of alternatives is not determined prior to decision-making. Multi Objective Optimization (MOP) is a type of MODM. Here, the decision making models provide the best situation of decision factors to reach the maximum fulfilment of objectives. Energy management, concept selection, construction, and transportation are some examples of MODM. (Amiri, Abtahi, & Khalili-Damghani, 2013; Bonilla-Petriciolet, Rangaiah, & Segovia-Hernandez, 2011; Cortes, Saez, Milla, Nunez, & Riquelme, 2010; Deb et al., 2012; Gamberini, Gebennini, Manzini, & Ziveri, 2010; Guo, Zhan, & Wu, 2012; Khalili-Damghani, Abtahi, & Tavana, 2013; Savic & Stefanov, 2012; Sayyaadi & Amlashi, 2010).

ii) Multi Attribute Decision Making (MADM): They are decision makings with discrete environment. In this type of decision making, the managers or systems possess information regarding alternatives, criteria, and the ability of alternatives in each criteria. Moreover, there are determined alternatives in MADMs, and the decision makers can just evaluate and rank the existing alternatives. Supplier selection, manufacturing, human resource management, environmental management, and risk management are some examples of MADMs. (Amin, et al., 2011; G. Buyukozkan, 2012; Donevska, Gorsevski, Jovanovski, & Pesevski, 2012; Ertugrul & Karakasoglu, 2009; Fouladgar, Yazdani-Chamzini, & Zavadskas, 2012; Iranzadeh, Ramezani, Heravi, & Norouzi, 2013; Xu, 2014; Zeydan, Colpan, & Cobanoglu, 2011).

2.3.1 (b) MCDM Methods

There are more than 30 recognized MCDM methods. However, the number of MCDM methods are not determined, since any method such as mathematical and statistical methods that can address MCDM is regarded as an MCDM method (Belton and Stewart, 2002). The MCDM methods are classified into two general groups based on their overall performance:

i) Outranking methods: Roy (1996) developed the outranking method with the presentation of the ELECTRE methods. The method allows one to conclude that alternative "a" outranks another alternative "b", when there are enough arguments to confirm that a is at least as good as b, and there is no essential reason to refuse this statement. PROMOTEE is another famous method within this classification.

ii) Non-outranking methods: Other MCDM methods, with the exception of outranking methods, are regarded as non-outranking methods. The most well-known non-outranking methods in this category are AHP (Analytic Hierarchy Process), TOPSIS (Technique for Order-ing Preferences Simulation to Ideal Solution), VIKOR, ANP, and DEMATEL.

2.3.2 Artificial Intelligent and MCDMs

Computerizing a decision-making process is effective, provided that the results resemble human decision making, at higher speeds and accuracies. Since the job of AI tools is to emulate human behaviors, they will be capable of improving the performance of computers in order to arrive at better decisions.

AI techniques are widely applied in science to provide high accuracy and flexibility. AI techniques are mostly classified as to Fuzzy Techniques(FT), Evolutionary Algorithms(EAs), Artificial Neural Networks (ANN), Case Base reasoning (CBR), and Expert System (ES). (Elam & Konsynski, 1987; Mellit & Kalogirou, 2008; Mellit, Kalogirou, Hontoria, & Shaari, 2009; Siddique, Yadava, & Singh, 2003).

In this section, we review the methods of applying AI techniques in MCDMs.

2.3.2 (a) Evolutionary Algorithms and MCDMs

Evolutionary Algorithms (EAs) is a type of computer search technique based on biological evolution. The input of these EAs is the problem and solutions coded according to a coding pattern named a "fitness function". This function evaluates candidate solutions, and then some of the best solutions generate new solutions, which lead to evolving solutions. Thus, the search space will evolve in the direction of the optimal solution (Ashlock, Schonfeld, Ashlock, & Lee, 2014).This optimal solution can be equal to the best decision recommended by a DSS.

Genetic Algorithm (GA) is the most popular type of EA (Holland, 1975), which uses evolution genetics as a pattern to solve problems. In complex decision making process such as MCDM, the EAs are able to consider all factors involved in the decision-making simultaneously in a fitness function. Evolutionary Algorithms are the best optimizer, and in multi-objective optimisation problems, they are widely being utilized (A. Abraham & Jain, 2005; Deb & Kumar, 2007; Durillo, Nebro, & Alba, 2010; Ishibuchi, Tsukamoto, & Nojima, 2008; Stewart, Janssen, & van Herwijnen, 2004).

We divide the methods of applying EA in MCDMs to three groups:

Group 1: The EA directly is applied to address MCDM. There are three techniques in this group, which are:

- Multi-criterion quantum programming (J. Balicki, 2009; J. M. Balicki, et al., 2010);
- Immune co-evolutionary algorithm (Ding, et al., 2011);
- Integrating evolutionary strategies with the co-evolutionary criteria evaluation model (Y.-H. Chang and Wu, 2011).

Group 2: The MCDM methods apply to optimize the performance of EAs. In this group, the MCDM methods are integrated with EAs for the purpose of improvements in several steps. There are three technological classifications in this group:

i) The MCDM methods are applied to calculate the fitness value or function (Chan, Chung, and Wadhwa, 2004, 2005);

ii) The MCDM method is applied to compare and evaluate individuals of population and alter multiple criteria into one fitness value (De Lit, Latinne, Rekiek, & Delchambre, 2001);

iii) The MCDM method is applied to classify the chromosomes in the population (Hu and Chen, 2011).

Group 3: The EA and MCDM method are applied in separate steps. There are two techniques in this group:

i) i) The model uses MCDM methods prior to EA to select one objective from multiple objectives. Therefore, the problem changes from multi-objective optimisation to single objective optimisation, and the GA solves the new single objective optimisation problem (Deb, Pratap, Agarwal, & Meyarivan, 2002).

ii) ii) The model uses MCDM methods after EA to select the best solution among the optimal solutions. These models normally used Prato-optimal (Aiello, Enea, & Galante, 2006; Guo, et al., 2012; Nandi, Datta, & Deb, 2012) or Non-dominated Sorting Genetic Algorithm (NSGA) (Malekmohammadi, Zahraie, and Kerachian, 2011) to obtain optimal solutions, then uses MCDM methods, such as ELECTRE to rank the solutions and selects the best. one.

The usual method of applying EAs in MCDM belongs to group 1, where The EA directly is applied to address MCDM. Also, Prato-optimal and NSGA are usual evolutionary techniques to solve MODM (Fig 2.9). The method of integrating

ELECTREE and PROMOTEE with MCDM methods is applicable to solve MODM (Appendix A).

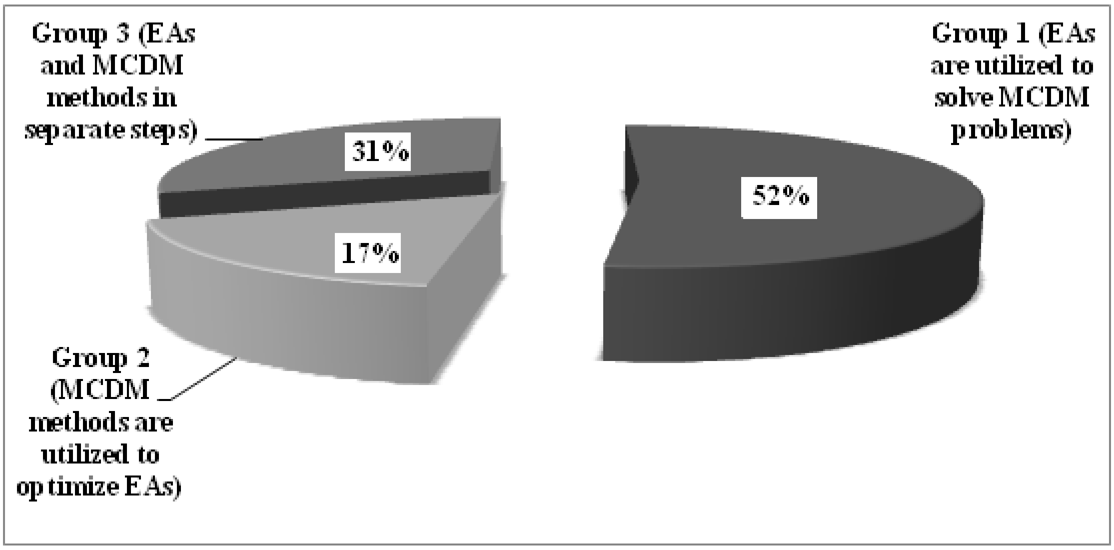


Figure 2.9: combination of MCDM and EA

2.3.2 (b) Artificial Neural Networks and MCDMs

Artificial Neural Networks (ANNs) usually addressed as Neural Networks (NNs), are mathematical or computational model inspired from biological neural networks. The objective of a neural network is to transform inputs into meaningful outputs. ANNs, while implemented on computers, are not programmed to perform specific tasks, instead, they are trained with respect to data sets until they learn the respective patterns.

The ANNs are directly applicable for certain problems, such as prediction, pattern classification, associative memories optimization, vector quantisation, and control applications (Kalogirou, 2001; Yegnanarayana, 2004). Accordingly, ANNs have been applied successfully in various fields, such as engineering, medicine, economics, and decision-making (Yegnanarayana, 2004).

ANN is a suitable technique for decision-making involving incomplete and uncertain information(s). In this kind of DMs, NN has the ability to complete the data using predictions, and deal with uncertainty as well. There are four groups of combination involving MCDM and ANNs:

Group 1: ANN is directly applied to solve MCDM problems. The ANN is applied individually to solve MCDMs. Here, using Feed-Forward Neural Network (FFNN) and Multilayer Perceptron (MLP) methods for MCDMs exceeds Back-Propagation Neural Network (BPNN) (Singh, Choudhury, Tiwari, & Shankar, 2007; Bolanca, Cerjan-Stefanovic, Lusa, Ukic, & Rogosic, 2010; Stefanovic, Bolanca, Lusa, Ukic, & Rogosic, 2012; J. Chen, Zhao, & Quan, 2008).

Group 2: ANN is applied to address the problems caused by gathering information from experts in MCDMs. Much information is needed during the decision-making process, with multiple criteria and alternatives that should be prepared based on the experts' opinion. Discussion with experts or decision-makers gather their opinion results in three problems. The first problem is that many interviews and questions from experts are required, which is very tedious, the second is the high probability of error caused by fatigue on the part of the experts, and the third is incomplete information on the part of the decision-maker.

In few methods, the ANN is used to address the aforementioned problems. ANN captures and represents the decision maker's preferences. The ANN gets an example of the preferences, and then determines other preferences for decision-making purposes.

In some methods, the FFNN approach is used to solve MADM problems. For this purpose, the ANN is used to capture and represent the decision maker's preferences, and then selecst the most desirable alternative (Malakooti & Zhou, 1994).

The recent methods mix ANN and MCDM methods. They use BPNN to express the preferences and knowledge of the decision makers, and then the MCDM methods to evaluate the alternatives (Jiang, Zhang, Yan, Zhou, & Li, 2012; Lakshmanpriya, Sangeetha, & Lavanpriya, 2013).

Group 3: The output of the ANN technique is regarded as a criterion in the decision-making problem, and MCDM methods are applied to evaluate the alternatives. In this group, there are different integration of ANN and MCDM methods, such as BPNN and TOPSIS (Araz, Eski, & Araz, 2006, 2008),and BPNN and PROMETEE (Ni, Chen, & Kokot, 2002).

Group 4: The MCDM methods are used to evaluate and select of the best ANN technique for special applications. There are various ANN techniques, and it is important that a suitable one be selected to address a specific problem. In doing this, many criteria are involved, so the MCDM methods can assist to evaluate and select the best ANN (I. Ahmad, A. Abdullah, & A. Alghamdi, 2010; I. Ahmad, A. B. Abdullah, & A. S. Alghamdi, 2010).

Fig 2.10 shows that method of applying NN in MCDM belonging to the third group is most common, where the output of ANN technique is regarded as a criterion in the decision-making problem, with the MCDM method being applied to solve the problem .

2.3.2 (c) Case Base Reasoning and MCDMs

Case Base Reasoning (CBR) is the process of solving new problems based on the solutions of similar previous problems. CBR is regarded as a prominent type of analogy making. The retrieve, reuse-revise, and retain procedures are known as the steps of the CBR cycle. In retrieving past cases that are similar to the current one and in reusing-revising, the past successful solutions are revised and reused. Then, the current solved case can be retained and placed into the system knowledge base as a case base or a case library (Aamodt & Plaza, 1994).

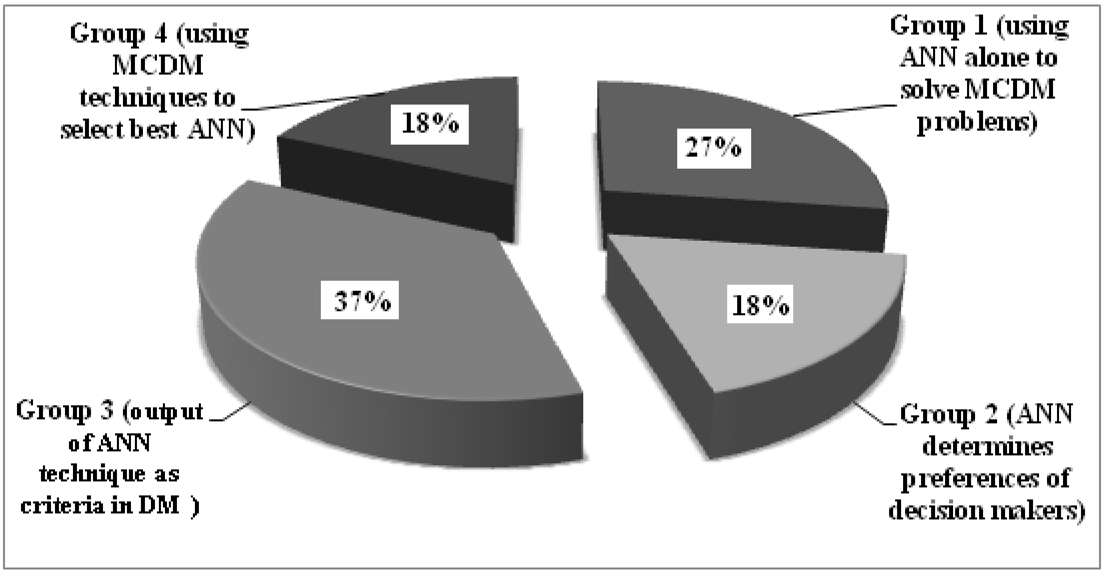


Figure 2.10: combination of MCDM and ANN

The CBR is used in intelligent DSS to emulate the human reasoning, and make decisions in similar decision-making situations (Watson and Marir, 1994). These techniques are suitable for decision-makings in similar cases. Some studies use CBR method for MCDMs. The recent studies, mostly integrate CBR method with the MCDM methods, such as AHP (Feng, Wang, Xu, & He, 2013; Kim, 2013; C. W. Xu, Yao, & Li, 2013), ANP (Wolfslehner & Vacik, 2011)and Simple Additive Weighting (SAW)(Abbasianjahromi & Rajaie, 2013)to speed up the process of case-matching and increase accuracies.

2.3.2 (d) Expert System and MCDMs

Expert System (ES) was developed in the 1960s as an AI technology to simulate human knowledge. It is a computer program designed to model the problem solving ability of human experts. ES greatly increased in popularity since their commercial introduction in the 1980s. Today expert systems are used in business, science, engineering, manufacturing, medicine and many other fields, where a well-defined problem domain exists (Ahmad, 2001) .

Expert systems are behind many decision-making processes in electronic manufacturing, banking, and energy planning. They are the examples of very successful applications of AI technology, especially for DSSs (Klein & Methlie, 1995). Related methods combine decision support technology and expert system technology to create a new framework named knowledge-based decision support system, which includes MCDM methods, such as AHP in their knowledge base to help support MCDMs (Beynon, Cosker, & Marshall, 2001; Chakraborty & Dey, 2006)(Fig 2.11). They use the Expert system for MCDM to obtain two important benefits from this AI technology; the first one is using a ES knowledge base to keep the expert's knowledge and related MCDM methods, rules, and the second one is using the inference engine for rational decision making process, such as human inferences.

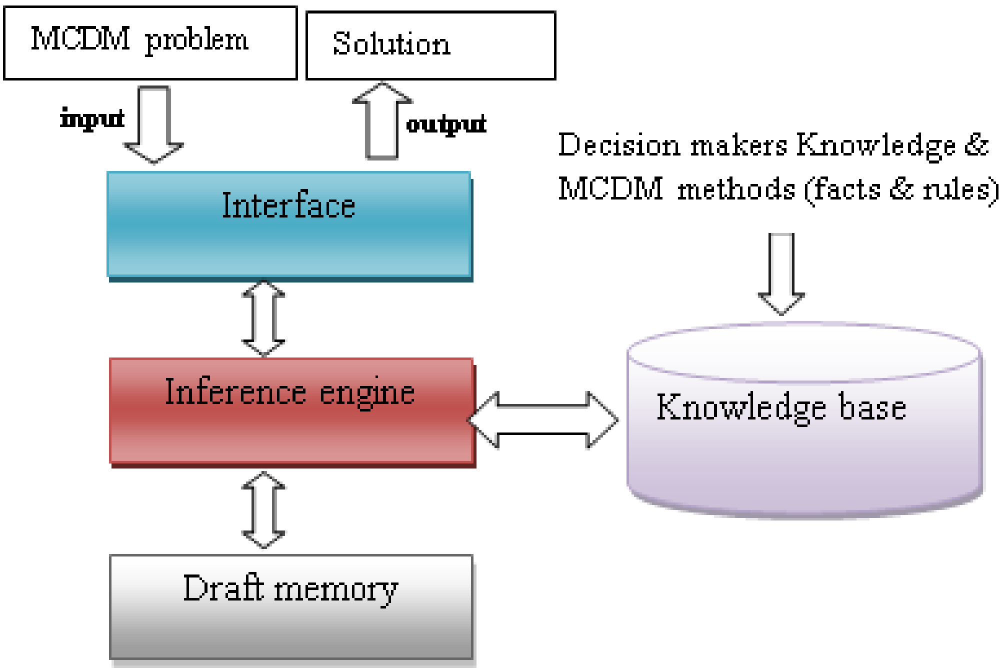


Figure 2.11: Knowledge based decision support system for MCDM

There is a method which integrates MCDM methods, ES, and Geographic Information System (GIS) to solve certain MCDM problems in a geographic area (J. He, et al., 2007; Yang, Liu, & Wang, 2007). The integration of the ES and MCDM methods is also applicable to solve psychological problems (Nunes, Pinheiro, Pequeno, and Dantas Pinheiro, 2010, 2011).

2.3.2 (e) Fuzzy Techniques and MCDMs

Fuzzy Techniques (FTs) are based on the fuzzy set theory (Zadeh, 1965), which solves the problem of uncertainty and ambiguity for computer systems with linguistic and vague variables. In intelligent DSSs, the aim is to simulate human thinking and make decisions as a human would in difficult settings. The DSS should refer to the expert's knowledge for decision-making, which will allow the expert's knowledge to be transferred to a computer.

Uncertainty is one of the important factors in the simulation of human knowledge and linguistics. Therefore, FTs are the most consonant AI tools with DSSs, and help import uncertainty and logic variable integrated with human knowledge to DSSs. Moreover, in the section (3.2), we prove that FT is the most proper AI technique to address supplier management. FTs widely utilized in MCDM methods for optimization purposes.

The approach resulted this combination named FMCDM (Fuzzy Multi-Criteria Decision Making) which is a subset of IMCDM.

Since this study focuses on FMCDM, we will review the development of FMCDM in terms of applications and applied fuzzy techniques. We use the Web of Science (WoS) search engine to cover a time period of 32 years, commencing from June 1980 to June 2013, and zooming on the keywords such as "Fuzzy Multi-Criteria Decision Making". In the first search, we found 718 documents. We limited the search results to articles published in five higher publication journals as expert systems with applications, fuzzy sets, and systems, such as the international journal of production research, European journal of operational research, and information sciences.

Finally, we found 142 articles regarding FMCDM (Appendix B). Reviewing these articles showed that differing FTs, such as alpha-cut, Intuitionistic fuzzy sets, Triangular Fuzzy Numbers (TFN), Trapezoidal Fuzzy Numbers (TPFN), and 2-type fuzzy sets have been applied in MCDMs. The defuzzification of linguistic variables for the input of MCDM methods is an important issue in MCDM, and using fuzzy numbers such TFN and TPFN is the mostly applied FTs in FMCDM (Fig 2.12).

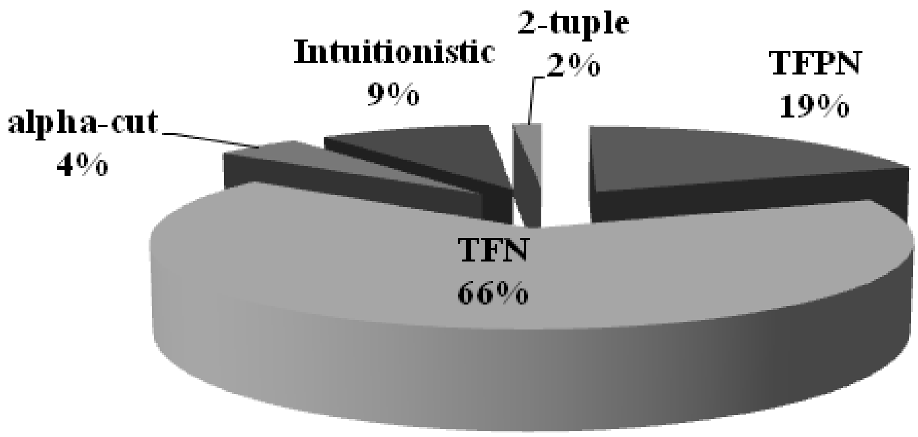


Figure 2.12: Applying FTs in FMCDMs

TFN uses three numbers, while TPFN uses four numbers to fuzzify linguistic variables. Therefore, using TPFN in MCDM with criteria such as decision makers, and alternatives will inevitably result in huge amounts of computations. Accordingly, in MCDMs involving levels of criteria, TFN is faster than TPFN (S.-M. Chen, 1996). Also, the Correlation Coefficient (CC) test signifies the suitability of TFN for supplier management. In the following section, we will explain the considered CC test and its corresponding results.

Correlation Coefficient (CC) is a statistical tool for determining the type and degree of relationship of a quantitative variable with another quantitative variable. CC is one of the factors used in determining the correlation between two variables (Croxton & Cowden, 1939). We use the Statistical Package for the Social Sciences (SPSS) to determine the CC between two variables.

The produced correlations table by SPSS displays the Pearson correlation coefficients, significance values, and the number of cases with non-missing values (N). The values of the correlation coefficient range from -1 to 1, and in the lack of relationship between two variables, zero. The sign of the correlation coefficient indicates the direction of the relationship (positive or negative).(Croxton & Cowden, 1939)

The absolute value of the correlation coefficient (r-value) indicates the strength, with larger absolute values indicating stronger relationships. The correlation coefficients on the main diagonal are always 1, because each variable has a perfect positive linear relationship with itself.(Croxton & Cowden, 1939)

The significance of each correlation coefficient is also displayed in the correlation table. The significance level (or p-value) is the probability of obtaining results as extreme as the one being observed. If the significance level is very small (less than 0.05), then the correlation is significant, and the two variables are linearly related, while if the significance level is relatively large (for example, 0.50), then the correlation is not significant, and the two variables are not linearly related.(Croxton & Cowden, 1939)

In section (3.2), we will prove that the Evaluation, Ranking and Selection (ERS) is required for supplier management. The correlation analysis of data (presented in appendix B) indicates a direct and strong linear relation between TFN and ERS if the P-value was below the magic .05, and the r-value was 0.981 (Table 2.2). Also, their correlation is significant at the 0.01 level (2-tailed).

Table 2.2: Correlation Coefficient of TFN and ERS

		ERS
TFN	Pearson Correlation (r-value)	0.981
	Sig. (2-tailed) (p-value)	0.003
	N	12

We also obtaine the CC of other FTs and ERS. The results showed that the TFN has the strongest relationship with ERS compared to other FTs (Fig 2.13).

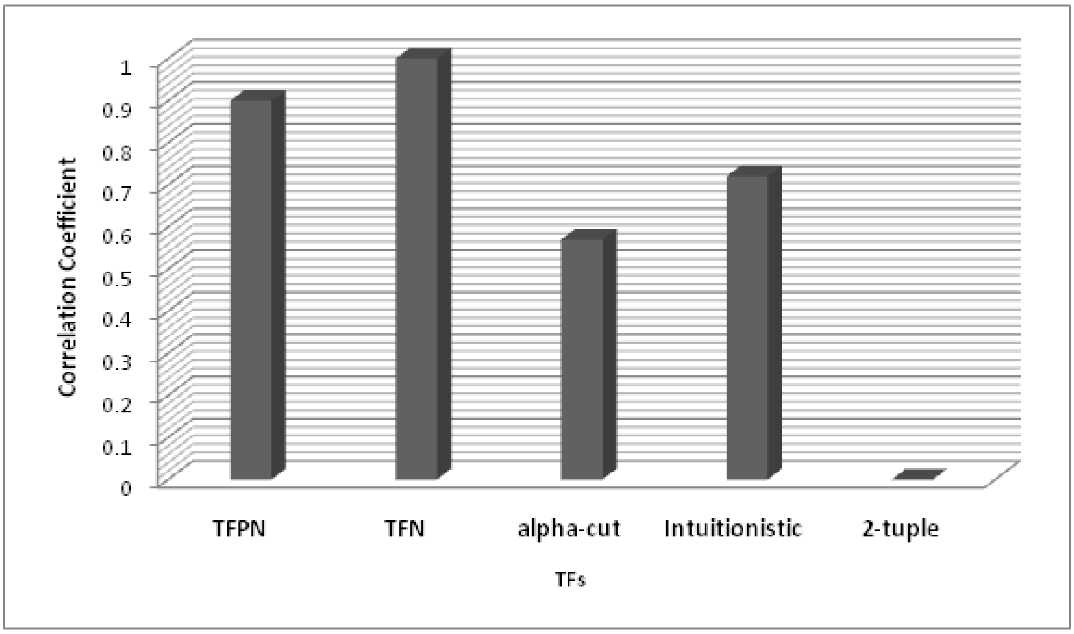


Figure 2.13: Correlation Coefficient of FTs and ERS

2.3.3 Basic definitions of fuzzy sets

Fuzzy set theory is an extension of classical set theory, which is used to defuzzify and computerize linguistic variables (Zadeh, 1965). In a classical set, an element can only have two possible states; member or non-member. However, in a fuzzy set, each element has a degree of membership, which is represented by fuzzy numbers. Here, some basic definitions of fuzzy sets based on TFN is provided (van Laarhoven & Pedrycz, 1983; Buckley, 1985; zimmermann, 2001; Dagdeviren & Yueksel, 2008; Amin & Razmi, 2009; Chang & Wang, 2009; Ertugrul & Karakasoglu, 2009; Oenuet et al., 2010).

Definition. 1: A fuzzy set $\tilde{A}$ in an universe of discourse X is characterized by a MF $\mu_{\tilde{A}}(X)$ that is associated with every element x in X a real number in the interval $[0,1]$. The function value $\mu_{\tilde{A}}(X)$ is termed the grade of membership of x in $\tilde{A}$.

Definition. 2: A TFN $\tilde{a}$ defines through a trio (l,m,u) as shown in Fig 2.14. The membership function $\mu_{\tilde{a}}(X)$ is defined.

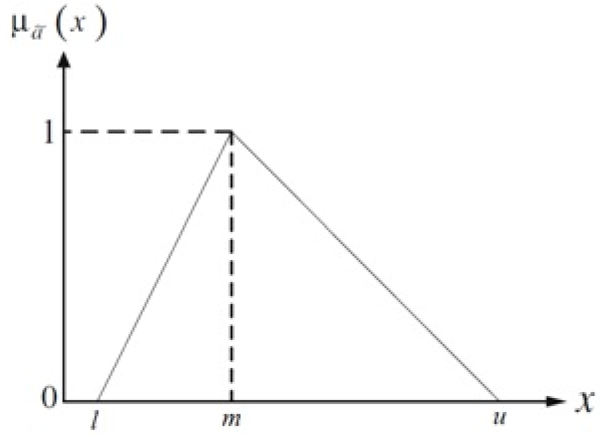


Figure 2.14: Triangular fuzzy number $\tilde{a}$

$$\mu_{\tilde{a}}(X) = \begin{cases} \frac{x-1}{m-1} & 1 \leq x \leq m \\ \frac{u-x}{u-m} & m \leq x \leq u \\ 0 & Otherwise \end{cases} \tag{2.1}$$

Let $\tilde{a}_1$ and $\tilde{a}_2$ be two TFNs defined through the trio (l_1, m_1, u_1) and (l_2, m_2, u_2) respectively, then the related operating rules are as follows:

$$\tilde{a}_1 + \tilde{a}_2 = (l_1, m_1, u_1) + (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{2.2}$$

$$\tilde{a}_1 - \tilde{a}_2 = (l_1, m_1, u_1) - (l_2, m_2, u_2) = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \tag{2.3}$$

$$\tilde{a}_1 \times \tilde{a}_2 = (l_1, m_1, u_1) \times (l_2, m_2, u_2) = (l_1 \cdot l_2, m_1 \cdot m_2, u_1 \cdot u_2) \tag{2.4}$$

$$\tilde{a}_1 / \tilde{a}_2 = (l_1, m_1, u_1) / (l_2, m_2, u_2) = (l_1 / l_2, m_1 / m_2, u_1 / u_2) \tag{2.5}$$

$$k \cdot \tilde{a} = (kl, km, ku) \tag{2.6}$$

Definition. 3: Linguistic variables are variables with linguistic term values. The concept of a linguistic variable is very useful in dealing with situations which are too complex or too ill-defined to be reasonably described in conventional quantitative expressions.

Definition. 4: Let $\tilde{a_1} = (l_1, m_1, u_1)$ and $\tilde{a_2} = (l_2, m_2, u_2)$ be two TFNs, then the vertex method is defined to calculate the distance between them.

$$d(\tilde{a_1}, \tilde{a_2}) = \sqrt{\frac{1}{3}\left[(l_1 - l_2)^2 + (m_1 - m_2)^2\right]} \tag{2.7}$$

Definition. 5: Considering the various importance levels of criteria, the fuzzy weighted normalized decision matrix is built as:

$$V = \left[\tilde{v_{ij}}\right]_{n \times J} \tag{2.8}$$

Where

- $\tilde{v}_{ij} = \tilde{p}_{ij} \star w_i$,
- P matrix defined as $P = \left[\tilde{p}_{ij}\right]_{n \times J}$, is corresponding matrix of alternative performing of $A = \left[A_j\right]_J$with regard to criteria $C = [C_i]_n$,
- A set of importance weight of criteria $W = [w_i]_n$.

Since the importance value of criteria and alternatives are the fuzzy values, it is necessary to solve a non-fuzzy value in calculations. The Median defuzzification method is a method to defuzzify the fuzzy values. This method is a quick defuzzification method, and it is widely used in the relative literature (Klir & Yuan, 1995).

Let $\tilde{a}$ be a TFNs defined through the trio (l,m,u). Then the following formula is used to deffuzzify the $\tilde{a}$ and convert it to a crisp number as a.

$$a = \frac{l+2m+u}{4} \tag{2.9}$$

Where, u is the right-end value of the fuzzy number, m is the middle value of the fuzzy number and l is the left-end value of the fuzzy number.

2.3.4 Fuzzy AHP method

The Analytic Hierarchy Method (AHP) is proposed by Saaty (1980). AHP method is an MADM method based on additive weighting, where a number of criteria are represented by their relative importance. This method is suitable for evaluating, ranking, and selecting complex DMs having multiple levels of criteria (Lin & Wu, 2008). AHP can be employed for the evaluation of the criteria as well as its alternatives.

Generally, AHP entails three stages:

i) Composing hierarchy decision tree: The complex DMs can be decomposed into hierarchical levels. A hierarchy has at least three levels: overall goal of the problem at the top, multiple criteria that define the alternatives in the middle, and the decision alternatives at the bottom.

ii) Constructing pairwise comparison matrices: The evaluation of criteria is based on pairwise comparison matrices. The importance of the criteria will be compared using judgment's opinions. Then, we obtain the relative importance of one criterion over another criterion using pairwise comparisons. The obtained importance will be used to construct a pairwise comparison matrix of criteria. Let $C = [C_i]_n$ $i = 1,2,...,n$

be the set of criteria. The result of the pairwise comparison is summarized in an evaluation matrix as:

$$CW = \begin{bmatrix} cw_{11} & \cdots & cw_{1n} \\ \vdots & \ddots & \vdots \\ cw_{n1} & \cdots & cw_{nn} \end{bmatrix} \tag{2.10}$$

Where $CW = \left[cw_{ij}\right]_{n\times n}$and cw_{ij} is the importance of the criterion C_i over criterionC_j.

iii) Weighting and ranking: The following steps calculate the weights and draw out the ranking from the pairwise comparison matrix:

Step 1: Squaring pairwise comparison matrix and construct $S = \left[s_{ij}\right]_{n\times n}$.

- Summarization row elements of matrix$S$ and construct vector$\overrightarrow{CS} = [cs_i]_n$where:

$$cs_i = \sum_{j=1}^{n} S_{ij} \tag{2.11}$$

Step 2: Normalization of vector$\overrightarrow{CS}$ to reach eigenvector$\overrightarrow{CN} = [cn_k]_n$ where:

$$cn_k = \frac{cs_k}{\sum_{i=1}^{n} cs_i} \tag{2.12}$$

Step 3: Iteration of steps 1-3 and comparing eigenvector in each iteration with previous one until differences between eigenvectors become very less. So the last eigenvector is the priority vector.

Eigenvector solutions are the best approach to get a ranking of priorities from a pairwise comparison matrix (Saaty, 1980). Therefore, the weighting of criteria will be concluded from the eigenvector $\overrightarrow{CN}$.

In this method, pairwise comparison matrices are filled based on experts' judgment, which creates two problems in this method; inconsistency and subjectivity. The high probability of the occurrence of inconsistency is when the judgments' of experts are inconsistent. Currently, the rates of inconsistency are calculated to determine reliability of the answers (J. J. Wang & Yang, 2007). Therefore, the principal eigenvalue λ_{max} is used to calculate the ratio of inconsistency. This value is obtained from the summation of the product between each element of the priority vector $\overrightarrow{CN}$ and the sum of columns of the pairwise comparison matrix (Wang et al., 2009).

$$\lambda_{max} = \sum_{k=1}^{n} \sum_{i=1}^{n} cw_{ik} cn_k \tag{2.13}$$

The relation between CW entries determines the inconsistency index II as:

$$II = \frac{\lambda_{max} - n}{n - 1} \tag{2.14}$$

When $\lambda_{max} = n$, it means that the answers are completely consistent. Therefore, the ratio of inconsistencyIR achieves by dividing inconsistency index II by random index RdI as:

$$IR = \frac{II}{RdI} \tag{2.15}$$

The reliability of the results of AHP is strictly related to the ratio of inconsistency. If IR is more than 0.1 then the results cannot be reliable.

The reliability of the results of AHP is strictly related to the ratio of inconsistency. If IR is more than 0.1, then the results cannot be reliable. In the pairwise comparison step of the AHP method, the experts express their opinions in terms of linguistic variables. The linguistic variables are in turn associated with subjectivity. The AHP model does not consider the subjectivity of human judgments, while this greatly influences the results of

AHP, making it inaccurate (Yang & Chen, 2004). Currently, there are some studies that use the fuzzy extension of the AHP theory (Calabrese, Costa, & Menichini, 2013; Felix T. S. Chan & Kumar, 2007; C. Kahraman, Cebeci, & Ruan, 2004; Cengiz Kahraman, et al., 2003; Li, Wong, & Kwong, 2013; Tsaur, Chang, & Yen, 2002).

The fuzzification of AHP has different methods due to the fact that:

- Fuzzification of AHP in different phases, such as criteria weighting and alternative evaluating.

- Different fuzzification, such as applying different fuzzy MFs or defining various fuzzy linguistic variable scales.

2.3.5 Fuzzy TOPSIS method

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method was proposed by Hwang and Yoon (1981), and is one of the famous and usable MCDM methods. The TOPSIS method uses the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS) to reach the best alternative.

PIS involve maximum benefit criteria and minimum cost criteria, while NIS involves exactly the opposite (Abo-Sinna and Amer, 2005).

The TOPSIS method performs well in solving some types of decision-making problems. The literature shows that TOPSIS is the best method to alter rankings when a non-optimal alternative arrives, hence, in DM with a high probability of re-ranking, the result of TOPSIS is regarded as being more reliable (Alavi & Alinejad Rokny, 2011). In certain applications, the TOPSIS method is integrated with TOPSIS to increase the accuracy of DM. The Fuzzy TOPSIS (FTOPSIS) method was initially proposed by Yong (2006) in order to evaluate and select a plant location.

The strategy of evaluation in FTOPSIS is similar to TOPSIS. However, in FTOPSIS, the matrices are fuzzified, and the fuzzy definitions are used in calculations (Oenuet & Soner, 2008; Dagdeviren et al., 2009). Generally, FTOPSIS entails the following steps:

Step 1: Construct matrix P, as defined above. The fuzzy linguistic performance rating $(\tilde{p}ij)$ keeps the capability of alternatives in form of difuzzified TFNs which are normalized and belong to [0, 1]; Thus, the normalization is not necessary.

Step 2: Affect the weights on normalized fuzzy decision matrix. The weighted normalized value $\tilde{v}ij$ is calculated by $\tilde{v}_{ij} = \tilde{p}_{ij} \star w_i$, as mentioned in definition. 5.

Step 3: Identify fuzzy positive-ideal (A^*) and fuzzy negative ideal (A^-) solutions using the following equations:

$$A^* = [\tilde{v}_i^*]_n = \left[\left(max\, v_i \mid i \in I^{'}\right) \times \left(min\, v_i \mid i \in I^{''}\right)\right]_n \tag{2.16}$$

$$A^- = \left[\tilde{v}_i^-\right]_n = \left[\left(max\, v_i \mid i \in I^{''}\right) \times \left(min\, v_i \mid i \in I^{'}\right)\right]_n \tag{2.17}$$

Where $I^{'}$ is related to benefit criteria and $I^{''}$ is related to cost criteria.

Step 4: Measure the distance of each alternative from A^* and A^- using these equations:

$$D_j^* = \sum_{j=1}^{J} d\left(\tilde{v}_{ij}, \tilde{v}_i^*\right)\ i = 1, 2, \ldots, n,\ j = 1, 2, \ldots, J \tag{2.18}$$

$$D_j^- = \sum_{j=1}^{J} d\left(\tilde{v}_{ij}, \tilde{v}_i^-\right)\ i = 1, 2, \ldots, n,\ j = 1, 2, \ldots, J \tag{2.19}$$

Step 5: Calculate the similarity to ideal solution.

$$CC_j^- = \frac{D_j^-}{D_j^* + D_j^-} \; j = 1,2,\ldots,J \tag{2.20}$$

Step 6: Rank alternatives, according to CC_j^- in descending order and select the alternative with maximum CC_j^- .

2.4 Summary

In this chapter, we discovered that Hybrid Models (HMs), which are integrations of Artificial Intelligence Based Models and Linear Weighting Models (LWMs), can address the requirement of SES in this study. Therefore, we analyzed the methods of applying AI tools for multi-criteria decisions, and found that:

- The usual method of applying EAs in MCDM belongs to group 1, where The EA directly is applied to address MCDM. Also, Prato-optimal and NSGA are usual evolutionary techniques to solve MODM. The method of integrating ELECTREE and PROMOTEE with MCDM methods is applicable to solve MODM.
- • The most combinations of ANN and MCDM belong to group 3, where the output of ANN technique is regarded as a criterion in decision-making problem, and MCDM methods are applied to evaluate alternatives.
- • CBR technique is suitable for decision makings for previously established cases.
- • In the combination of ES and MCDM, ES knowledge base is used to keep the expert's knowledge, as well as the related MCDM methods' rules, and the inference engine for rational and making decision, such as human inferences.
- • Since the defuzzification of linguistic variables for the input of MCDM methods is an important issue in MCDM, using fuzzy numbers such TFN and TPFN are

the most applied FTs in FMCDM. TFN uses three numbers, while TPFN uses four numbers for the purpose of fuzzifying linguistic variables. Therefore, using TPFN in MCDM with various criteria, decision makers, and alternatives, results in huge numbers of computations. TFN is faster than TPFN, as well, having a higher CC than ERS.

MADM methods are a subset of LWMs. AHP and TOPSIS are two famous MADM methods. AHP is a suitable MADM method for evaluation, ranking, and selection of complex DMs, which might have multiple levels of criteria. In this method, pairwise comparison matrices are completed based on experts' judgment, which create two problems with this method; inconsistency and subjectivity.

TOPSIS is the best MADM method of ranking when a non-optimal alternative arrives, hence in DM with high probability of re-ranking; the result of TOPSIS is regarded as more reliable. FAHP and FTOPSIS have been proposed to deal with uncertainty in conventional AHP and TOPSIS.

CHAPTER 3

ANALYSIS OF AI BASED MCDM METHODS FOR SUPPLIER MANAGEMENT

3.1 Introduction

The best methods for applications are the most suited methods for them. In previous chapter we showed that among various applied methods and techniques for SES, the AI and MCDM methods have the highest applicability and efficiency.

In this chapter, in first section we analysis the literature of applying AI techniques in MCDMs i) to find the required operations for SES, ii) to determine the most suitable AI and MCDM methods which can fulfill the SES requirements and iii) to find the best type of hybridization for selected MCDM and AI methods. We identify the Fuzzy AHP and TOPSIS method as candidate methods for SES.

In second section, We define the environment of decision making. Then we analysis the manner of fuzzy AHP and TOPSIS method in changing the elements of environment. We find their strengths and limitations in different situations. The problems of these methods for supplier management are expressed in this section.

3.2 Supplier management needs and candidate methods

In this section we review the articles related to AIBM to identify suitable AI techniques and MCDM methods for SES. The population of this review includes all ISI papers from 2002-2013, related to AI and MCDM topics through search in Web of Science (WoS). We limit the search result with refine the documents to only English articles. Then we reviewed the abstract of refined articles to remove unrelated articles. Finally, we reviewed 207 articles, which is involving: 88 articles in FTs, 75 articles in EAs, 24 articles in ANNs, 11 articles in CBR and 9 articles in ES (Fig 3. 1).

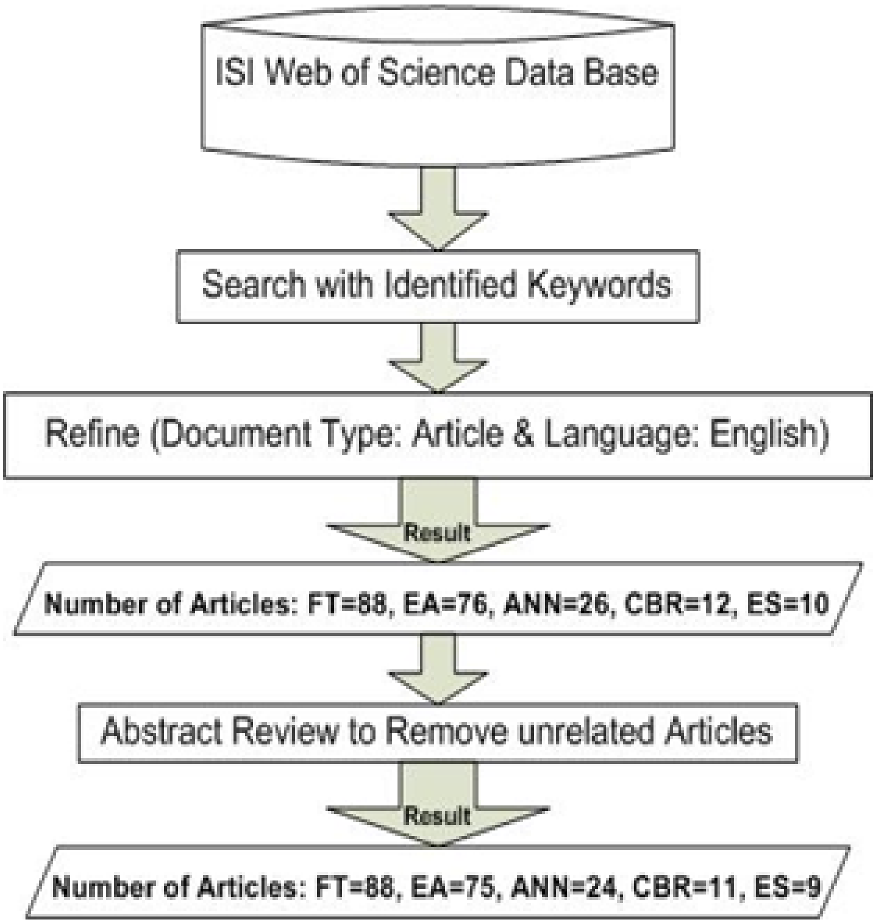


Figure 3.1: Flowchart of collecting related article

We reviewed the articles and investigated the following information in each article. Then we organized the investigations along with citation of articles in a table which is represented in appendix C. The considered information are:

- **Type of MCDM**; This is involving two options as Multi Objective Decision Making (MODM) and Multi attribute Decision Making (MADM). When the environment of decision making is discrete and situation of alternatives is determined before decision making, then we consider it as MADM. However, if the environment is continues and the situation of alternatives is not determined before decision making then we consider it as MODM.

- **Operation**; Depending on decision making in articles, different operations are conducting by AI and MCDM methods. We categorized the following operations from articles as: prediction, ranking, scheduling, selection, evaluation, optimization, assessment, allocation, comparison, planning, designing, classification and modeling.

- **Application**; We also reviewed the articles to find their related applications. We categorized all the applications of AI and MCDM methods which were involved in articles as: concept selection, supplier selection, Manufacturing, industries, risk management, economy, military, environmental, management, project/service management, information management, medical, location selection, human resource management, transportation, energy management and construction.

- **MCDM Methods**; We categorized MCDM methods as: outranking methods and non-outranking methods. Outranking methods involve PROMETHEE and ELECTRE methods. Non-outranking methods involve AHP, TOPSIS, DEMATEL, VIKO and ANP.

- **Types of hybridization AI techniques and MCDM methods**; In articles sometimes the methods are combined and sometimes they are integrated which it has two different meaning. In this study, we used "hybridization" word as a general word to represent both combination and integration of two methods.

  According to the articles the type of hybridization AI and MCDM methods is categorized to four types as:

  T1) AI technique is applied alone for multi-criteria decision-makings. In this type, AI technique does not integrate or combine with any MCDM methods while it may combines with other techniques.

  T2) AI technique combines with MCDM methods in separate steps. In this type, one technique uses the output of another technique for multi-criteria decision-making.

T3) AI technique is integrated with MCDM methods for multi-criteria decision making. T4) MCDM methods apply to increase the efficiency of AI technique.

Statistical analyzing of above information guides us to find appropriate method for any application such as SES. The process is explained in follow.

3.2.1 Methodology of finding candidate AI and MCDM method for supplier management

The candidate methods for supplier management address the supplier management needs. Candidacy of a method is determined based on relation between supplier management needs and method' ability. Supplier management needs involve the operations which should be proceed for SES. A method which is able to conduct these operations can be a candidate method for supplier management.

We investigate the relation between operations and methods by using the **correlation analysis** in SPSS (Statistical Package for the Social Sciences). Correlations measure how variables are related. We conduct the correlation analysis of data using *Pearson's Correlation Coefficient (CC)* (the normality of data is approved using Kolmogorov–Smirnov test)(Appendix D). A bigger CC indicates a stronger relationship between variables. Therefore, a method with biggest CC with supplier management requirements signifies as a candidate method.

The data analysis involves the following steps:

- **step 1:** Obtaining the correlation coefficients of supplier management with MCDM types and operations, to find the most related types and operations to supplier management. We hold out them as *SES types and operations*. These operations are the required operations for supplier management.

- **step 2:** Obtaining the correlation coefficients of AI techniques with SES types and operations, to find the candidate AI technique for supplier management.

- **step 3:** Obtaining the correlation coefficients of MCDM methods with supplier management, to find the candidate MCDM methods for supplier management.

- **step 4:** Obtaining the correlation coefficients of hybridization types of AI with MCDM methods, to find the suitable way to hybridize candidate AI and MCDM method.

In the following sections we represent the results of analyzing the above mentioned articles.

3.2.2 Required operations for supplier management

Through the critical review, we found that the name of application such "supplier selection" does not indicate to exact operations doing on application. Therefore, we recognized all MCDM operations of mentioned articles. Then, we obtained the Correlation Coefficient (CC) of various MCDM operations and SES application (Table 3.1).

Table 3.1: CC of MCDM operations and supplier management

Operation	Pearson CC (r-value)	p-value	N
Prediction	0.224	0.118	12
Ranking	0.804	0.000	12
Scheduling	-0.128	0.376	12
Selection	0.917	0.000	12
Evaluation	0.850	0.000	12
Optimization	0.20	0.02	12
Assessment	0.070	0.210	12
Allocation	0.200	0.04	12
Comparison	0.596	0.034	12
Planning	-0. 200	0.160	12
Designing	0.012	0.433	12
Classification	0.150	0.046	12
Modeling	0.301	0.034	12

Table 3.1 displays Pearson correlation coefficients (r-value), significance values (p-value), and the number of cases with non-missing values (N) for correlation between MCDM operations and supplier management. The data is collected for 12 years (2002-2013), so the value of N is 12.

The result of correlation analysis in table 3.1 shows that the selection operation with $r - value = 0.917$ has very strong and linear relation with supplier management. The p-value for selection is less than 0.01, so the correlation is significant at the 0.01 level.

The evaluation operation with $r - value = 0.850$ has very strong and linear relation with supplier management. The p-value for evaluation is less than 0.01, so the correlation is significant at the 0.01 level.

Also, The ranking operation with $r - value = 0.804$ has very strong and linear relation with supplier management. The p-value for evaluation is less than 0.01, so the correlation is significant at the 0.01 level.

Accordingly, the "selection", "evaluation" and "ranking" operations, in order have the strongest and linear relationship with supplier management. Therefore, the most required operations for supplier management are *Ranking and Selection which we nominated as "ERS".*

3.2.3 AI techniques and Supplier management operations

We tested the relation between AI techniques and supplier management operations by calculating the CC of number of AI articles and number of conducting ERS in these articles. In this case we show the process of obtaining CC in SPSS software. Fig. 3.2 shows the entire data which are obtained from table of reviewing AI based methods (Appendix C). Figures 3.3, 3.4, 3.5 and 3.6 shows the process of obtaining CC in SPSS.

The relation between an AI technique and supplier management operations signifies the suitability of considered AI technique for supplier management.

Table 3.2 displays Pearson correlation coefficients (r-value), significance values (p-value), and the number of cases with non-missing values (N) for correlation between SES operations and AI techniques. The data is collected for 12 years (2002-2013), so the value of N is 12.

Year AI techniques	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2002-2013
FT	1	3	3	2	2	9	9	10	9	21	26	24	
ERS No.	1	5	2	1	4	10	12	18	12	27	28	28	
EA	0	3	2	6	3	4	5	6	16	14	16	18	
ERS No.	0	0	1	1	0	0	0	0	1	2	1	1	
ANN	2	1	1	0	1	3	1	3	3	5	2	0	
ERS No.	2	0	2	0	0	2	1	0	2	2	2	0	
ES	0	0	0	1	2	1	0	1	3	1	3	4	
ERS No.	0	0	0	1	1	0	0	0	2	0	2	2	
CBR	0	0	0	2	1	0	0	1	1	4	2	2	
ERS No.	0	0	0	3	1	0	0	1	0	2	3	2	
Total	ERS No.: /papers No.:												

Figure 3.2: Number of conducting Evaluation, Ranking or Selection operations (ERS)

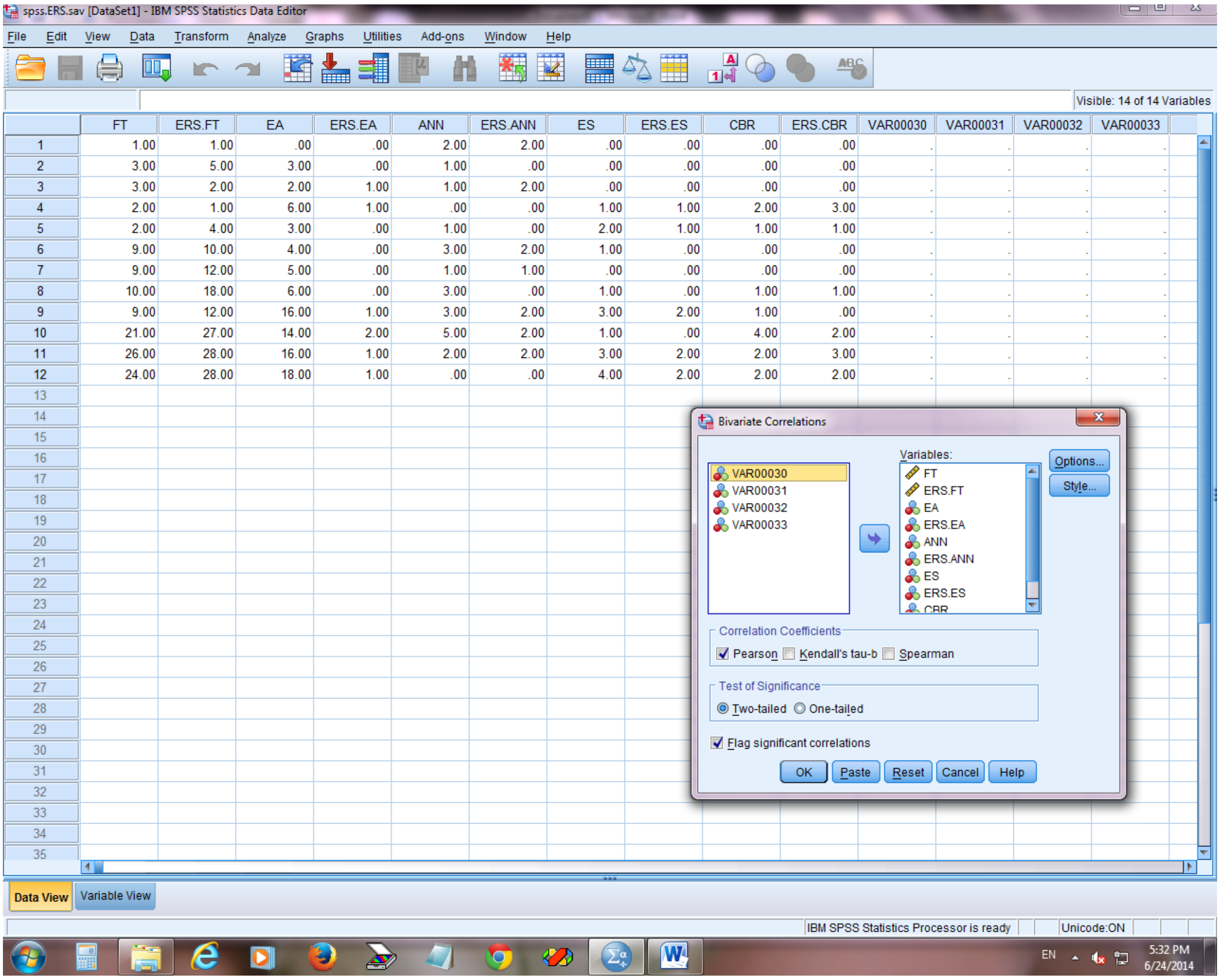
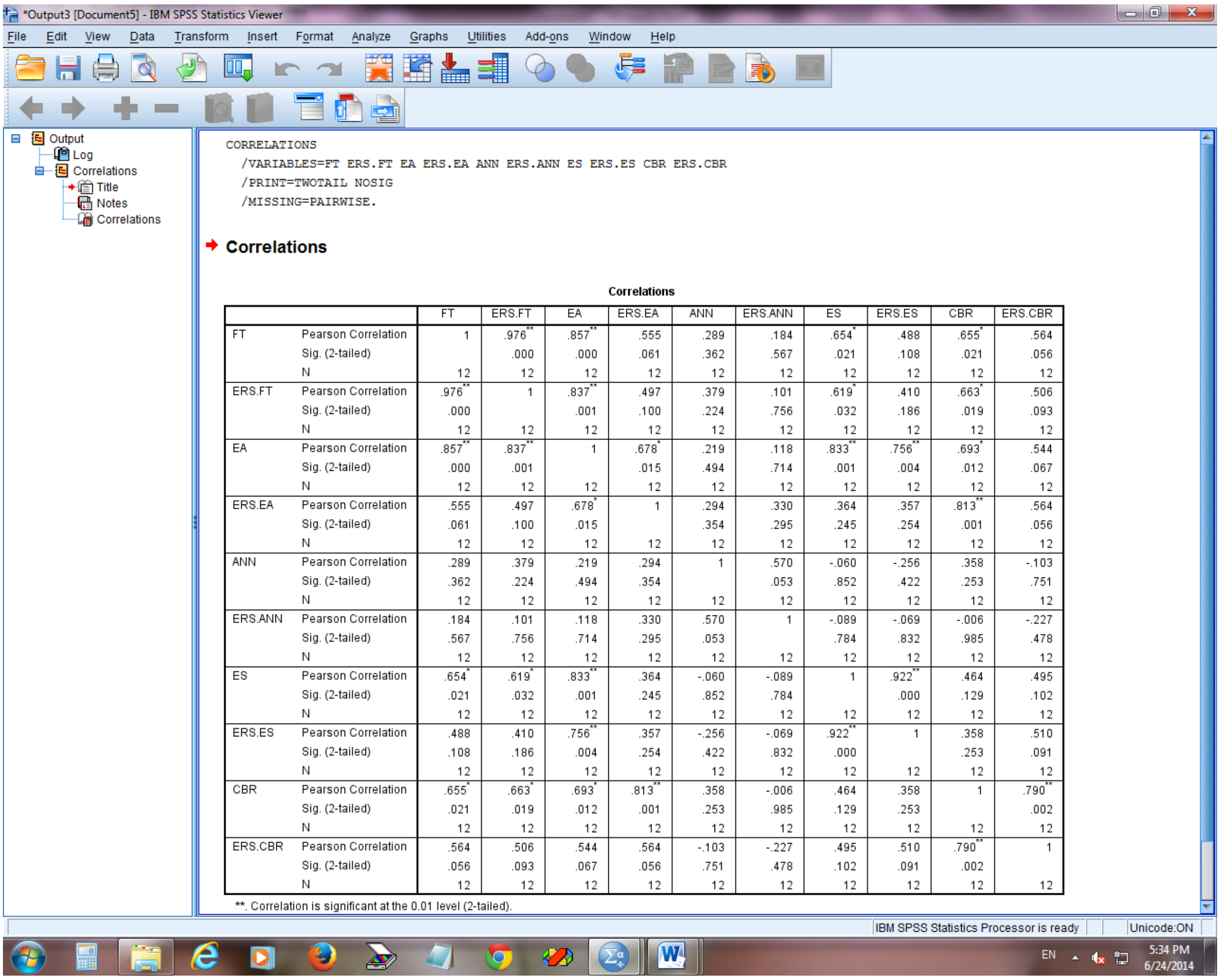


Figure 3.3: Setting value of variables



```
CORRELATIONS
  /VARIABLES=FT ERS.FT EA ERS.EA ANN ERS.ANN ES ERS.ES CBR ERS.CBR
  /PRINT=TWOTAIL NOSIG
  /MISSING=PAIRWISE.
```

Correlations

Correlations

		FT	ERS.FT	EA	ERS.EA	ANN	ERS.ANN	ES	ERS.ES	CBR	ERS.CBR
FT	Pearson Correlation	1	.976**	.857**	.555	.289	.184	.654*	.488	.655*	.564
	Sig. (2-tailed)		.000	.000	.061	.362	.567	.021	.108	.021	.056
	N	12	12	12	12	12	12	12	12	12	12
ERS.FT	Pearson Correlation	.976**	1	.837**	.497	.379	.101	.619*	.410	.663*	.506
	Sig. (2-tailed)	.000		.001	.100	.224	.756	.032	.186	.019	.093
	N	12	12	12	12	12	12	12	12	12	12
EA	Pearson Correlation	.857**	.837**	1	.678*	.219	.118	.833**	.756**	.693*	.544
	Sig. (2-tailed)	.000	.001		.015	.494	.714	.001	.004	.012	.067
	N	12	12	12	12	12	12	12	12	12	12
ERS.EA	Pearson Correlation	.555	.497	.678*	1	.294	.330	.364	.357	.813**	.564
	Sig. (2-tailed)	.061	.100	.015		.354	.295	.245	.254	.001	.056
	N	12	12	12	12	12	12	12	12	12	12
ANN	Pearson Correlation	.289	.379	.219	.294	1	.570	-.060	-.256	.358	-.103
	Sig. (2-tailed)	.362	.224	.494	.354		.053	.852	.422	.253	.751
	N	12	12	12	12	12	12	12	12	12	12
ERS.ANN	Pearson Correlation	.184	.101	.118	.330	.570	1	-.089	-.069	-.006	-.227
	Sig. (2-tailed)	.567	.756	.714	.295	.053		.784	.832	.985	.478
	N	12	12	12	12	12	12	12	12	12	12
ES	Pearson Correlation	.654*	.619*	.833**	.364	-.060	-.089	1	.922**	.464	.495
	Sig. (2-tailed)	.021	.032	.001	.245	.852	.784		.000	.129	.102
	N	12	12	12	12	12	12	12	12	12	12
ERS.ES	Pearson Correlation	.488	.410	.756**	.357	-.256	-.069	.922**	1	.358	.510
	Sig. (2-tailed)	.108	.186	.004	.254	.422	.832	.000		.253	.091
	N	12	12	12	12	12	12	12	12	12	12
CBR	Pearson Correlation	.655*	.663*	.693*	.813**	.358	-.006	.464	.358	1	.790**
	Sig. (2-tailed)	.021	.019	.012	.001	.253	.985	.129	.253		.002
	N	12	12	12	12	12	12	12	12	12	12
ERS.CBR	Pearson Correlation	.564	.506	.544	.564	-.103	-.227	.495	.510	.790**	1
	Sig. (2-tailed)	.056	.093	.067	.056	.751	.478	.102	.091	.002	
	N	12	12	12	12	12	12	12	12	12	12

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 3.4: Correlations

The result of correlation analysis in table 3.2 shows that the FTs with $r - value = 0.976$ have very strong and linear relation with the supplier management operations (ERS). The p-value for selection is less than 0.01, so the correlation is significant at the 0.01 level. Therefore, the strongest candidate AI techniques for supplier management are FTs.

Table 3.2: CC of supplier management operations and AI techniques

AI technique	Pearson CC (r-value)	p-value	N
FTs	0.976	0.000	12
EAs	0.678	0.015	12
ANNs	0.570	0.053	12
CBR	0.790	0.002	12
ES	0.922	0.000	12

Figure (3.7) is a scatterplot to show the correlate differences between AI techniques and ERS. The X axis is the number of articles in different AI techniques and the Y axis

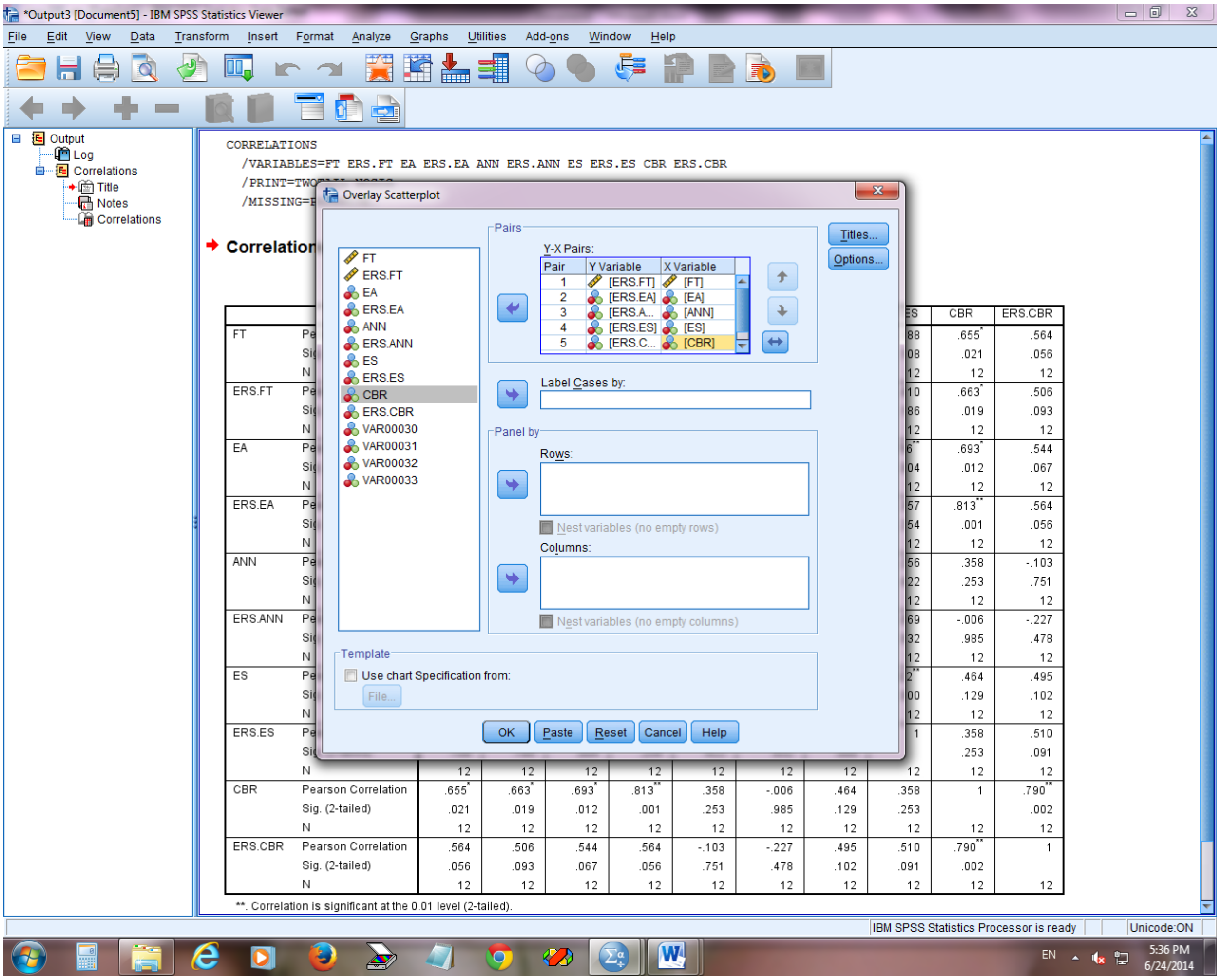


Figure 3.5: Selection of variables for scatterplot

is the number of conducting ERS in considered articles. It indicates that the number of conducting ERS in FTs' articles has a strongest linear relation with the number of articles in FTs.

Moreover, in chapter 2, we compared the applicability of FTs for supplier management with other AI techniques. We proved that FTs is more preferable than other AI techniques for supplier management. Therefore, we focused on area of FMCDM (Fuzzy Multi-Criteria Decision Making).

3.2.4 MCDM methods and Supplier management operations

Since applying a MCDM method in SES papers has relation with the number of SES papers, it can be considered as a candidate method for supplier management.

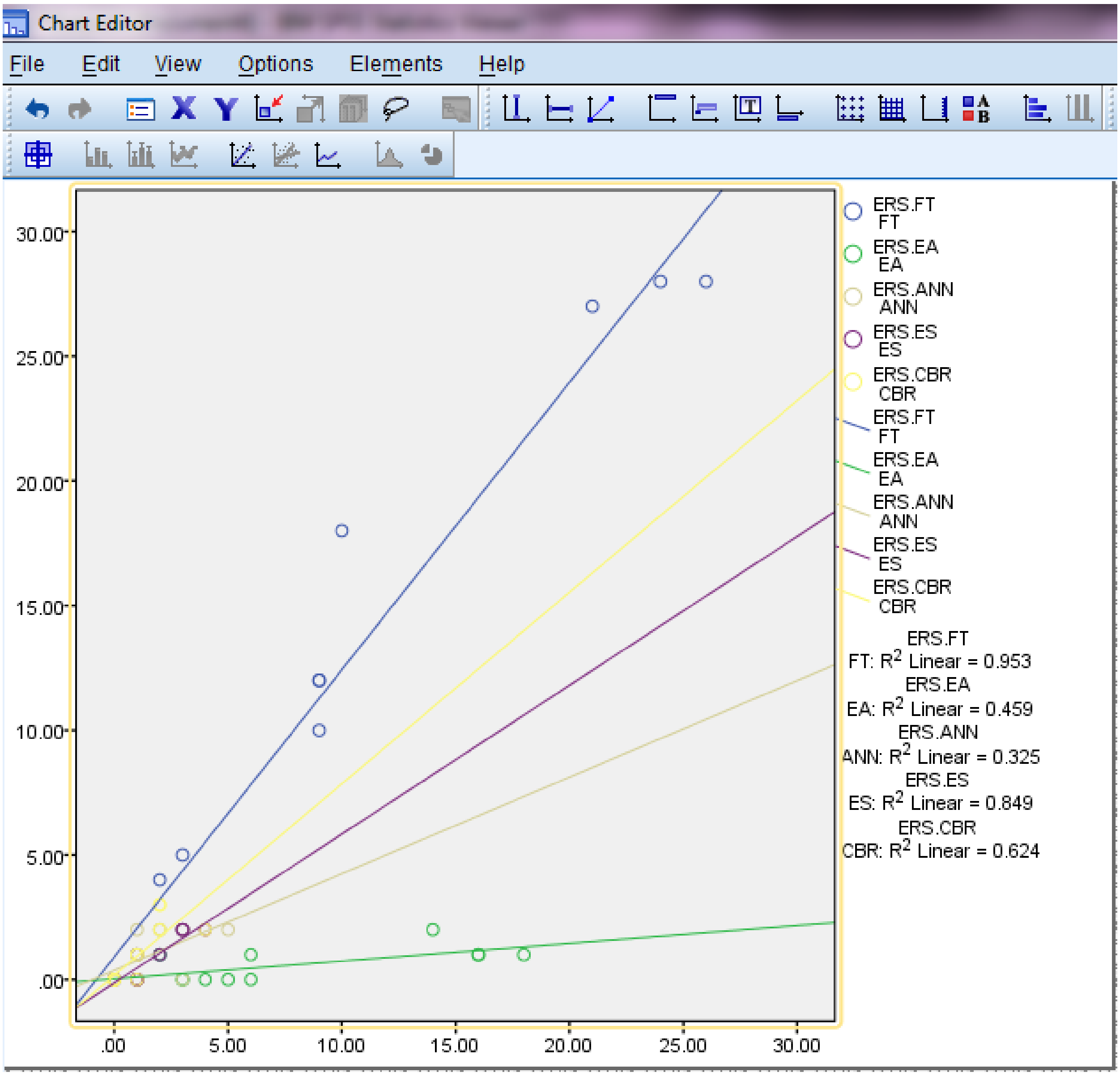


Figure 3.6: A perspective of CC scatterplot

Table 3.3 displays Pearson correlation coefficients (r-value), significance values (p-value), and the number of cases with non-missing values (N) for correlation between MCDM methods and supplier management. The data is collected for 12 years (2002-2013), so the value of N is 12.

The result of correlation analysis in table 3.3 shows that the AHP method with $r - value = .925$ has very strong and linear relation with supplier management. The p-value for AHP is less than 0.01, so the correlation is significant at the 0.01 level. Also, TOPSIS method with $r - value = .819$ has very strong and linear relation with supplier

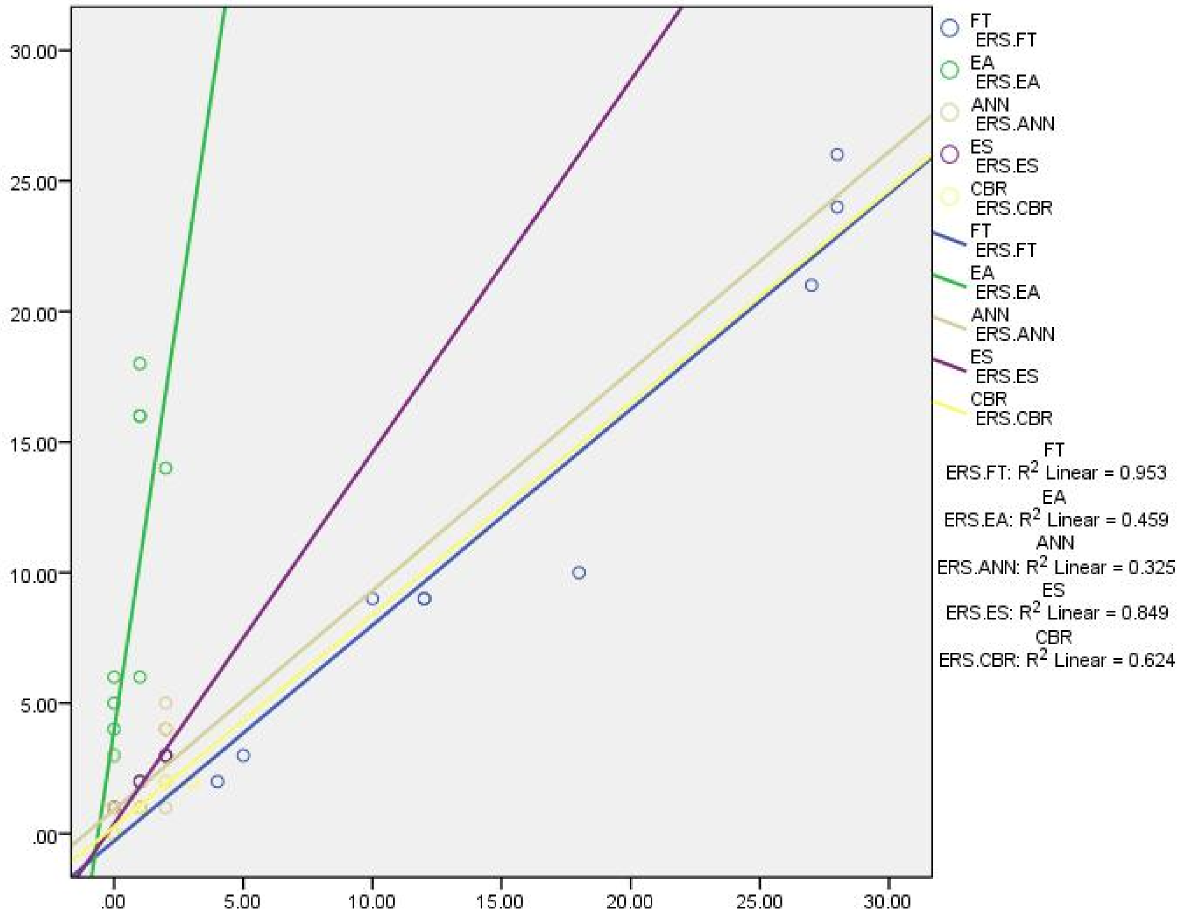


Figure 3.7: Scatterplot of correlation AI techniques and ERS operations

management. The p-value for TOPSIS is less than 0.01, so the correlation is significant at the 0.01 level.

Table 3.3: CC of MCDM methods and supplier management

MCDM Method	Pearson CC (r-value)	p-value	Number of cases
ELECTRE	0.062	0.848	12
PROMETHEE	0.311	0.325	12
ANP	0.062	0.848	12
AHP	0.925	0.000	12
VIKOR	-	-	12
DEMATEL	-	-	12
TOPSIS	0.819	0.001	0.68

The AHP and TOPSIS methods, in order have the strongest and linear relationship with supplier management. Therefore, they are the strong candidate MCDM methods to deal with supplier management.

Figure (3.8) illustrates the difference in correlation between various MCDM methods

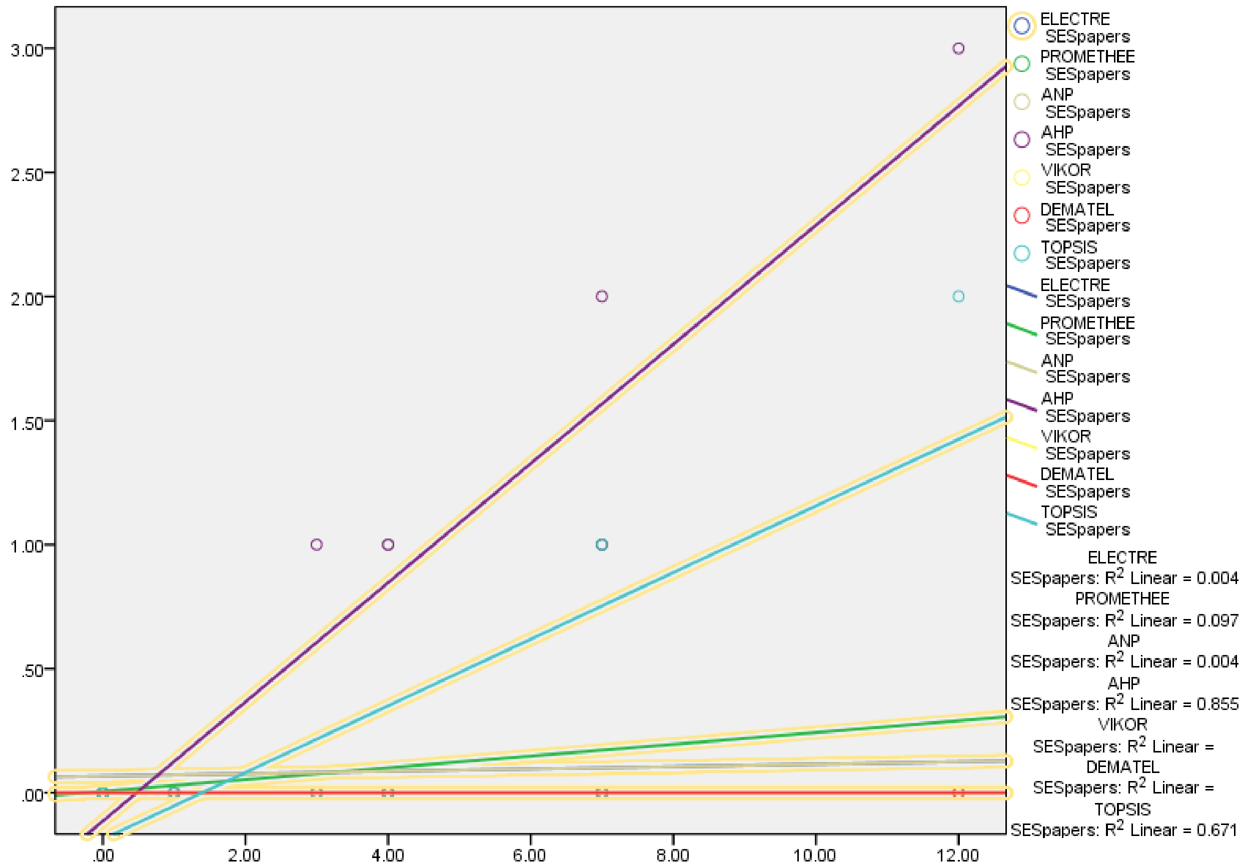


Figure 3.8: Scatterplot of correlation MCDM methods and supplier management

and supplier management. The X axis is the number of supplier management papers and the Y axis is the number of applying MCDM methods in considered papers. The AHP and TOPSIS methods have a big different with other MCDM methods to correlate with supplier management.

3.2.5 Hybridization of candidate methods

The hybridization of methods is a strategy to overcome their limitations and increase their abilities. As we discussed in section 2.2.3 the hybridization of AI techniques with other methods increases the accuracy of methods. Also, in section 2.3.2 we conclude that the hybridization of AI techniques with MCDM methods is applicable for supplier management.

The suitable AI technique and MCDM methods to supplier management is determined in section 3.2 as FTs, AHP and TOPSIS methods. In this section we analyze the correlation between various hybridization types and candidate methods. Then we determine the proper hybridization of FTs and candidate MCDM methods.

The articles are reviewed and we investigated the type of hybridization AI techniques and MCDM methods in each article (Appendix C). Through the critical review of papers we investigate the four types of hybridization between AI techniques and MCDM methods, as:

- Type 1 (T1): AI technique is applied alone for multi-criteria decision-makings. In this type, AI technique does not integrate or combine with any MCDM methods while it may hybridized with other techniques.
- Type 2 (T2): AI technique hybridizes with MCDM methods in separate steps. In this type, one technique uses the output of another technique for multi-criteria decision-making.
- Type 3 (T3): AI technique is integrated with MCDM methods for multi-criteria decision-making.
- Type 4 (T4): MCDM methods apply to increase the efficiency of AI technique.

Table 3.4 displays Pearson correlation coefficients (r-value), significance values (p-value), and the number of cases with non-missing values (N) for correlation between Hybridization types and fuzzy AHP methods. The data is collected for 12 years (2002-2013), so the value of N is 12.

Table 3.4: CC of Hybridization types and fuzzy AHP

Type of hybridization	Pearson CC(r-value)	P-value	N
T1	0.084	0.125	12
T2	0.463	0.013	12
T3	0.966	0.000	12
T4	0.021	0.117	12

The result of correlation analysis in table 3.4 shows that the T3 with $r-value = .966$ has very strong and linear relation with fuzzy AHP. The p-value for T3 is less than 0.01, so the correlation is significant at the 0.01 level. Therefore, the T3 is determined as proper hybridization of FT and AHP.

Table 3.5 displays Pearson correlation coefficients (r-value), significance values (p-value), and the number of cases with non-missing values (N) for correlation between Hybridization types and fuzzy TOPSIS methods. The data is collected for 12 years (2002-2013), so the value of N is 12.

Table 3.5: CC of Hybridization FTs and TOPSIS

Type of hybridization	Pearson CC(r-value)	P-value	N
T1	0.170	0.081	12
T2	0.553	0.008	12
T3	0.840	0.000	12
T4	0.056	0.164	12

The result of correlation analysis in table 3.4 shows that the T3 with $r-value = .840$ has strong and linear relation with fuzzy AHP. The p-value for T3 is less than 0.01, so the correlation is significant at the 0.01 level. Therefore, the T3 is determined as proper hybridization of FT and TOPSIS.

3.3 Analysis and comparison of fuzzy AHP and fuzzy TOPSIS

After extensive reviews and analysis SES methods in previous sections we concluded that Fuzzy AHP (FAHP) and Fuzzy TOPSIS (FTOPSIS) are candidate methods to apply for supplier management. However, still managers are not satisfied with the performance of these methods which is through their limitations and challenges in produce a high accurate results. In this section, technically we analyze these methods to discover their weaknesses and the way to improve them.

As we discussed in section 2.2.1, the decision methods are effected by environment changes and for different cases the suited decision method should be employed. The accuracy of a decision making model is high since it works based on the situations.

Then we define the environment of DM involving dynamic situations of decision and summarize the action of FAHP and FTOPSIS in this environment.

In sections 2.3.4 and 2.3.5 we explained the procedure of ranking by Fuzzy AHP and Fuzzy TOPSIS. Fuzzy AHP and Fuzzy TOPSIS are frequently used by researchers for ranking of alternatives (refer 2.3.4 and 2.3.5). However, they are not critically compared to see their performance in different situation of SES. In this section, the comparison of both methods is made based on the analysis of mathematical procedures considering the structure of the problem depicted by the illustrative application case.

In this section, we analyze and compare the performance of FAHP and FTOPSIS based on a set of required characteristics of the techniques so as to adequately deal with the problem of SES. These factors are dynamic that are changeable in different DMs and specially SESs.We considered them as situations of SES environment. The following factors were considered as:

Ability to deal with specialist alternatives. This factor is called as **homogeny** situation,

Ability to deal with **re-ranking**,

Population of criteria and alternatives

Ability to deal with **inconsistency**

We determine that under which conditions use of FAHP method is preferred and also, in what conditions using FTOPSIS is more effective.

Also FAHP and FTOPSIS are compared in static situations such inconsistency, decision process, computational complexity and supporting group decision making.

3.3.1 Ability to deal with specialist alternatives

In supplier evaluation and selection the type of suppliers are different in adequacy to criteria. When each supplier is the most prefer in a criteria, then we call it as specialist supplier. For instance a supplier proposes the cheapest price or a supplier has the best deliver service. In following we show the performance of both methods to deal with the specialist alternatives.

We assume a SES problem with three criteria as C1, C2, C3 with the same weight and three alternatives as A1, A2, A3. We evaluate the alternatives using both methods. In figure 3.9, Five TFNs are shown fuzzy membership function of rating alternatives.

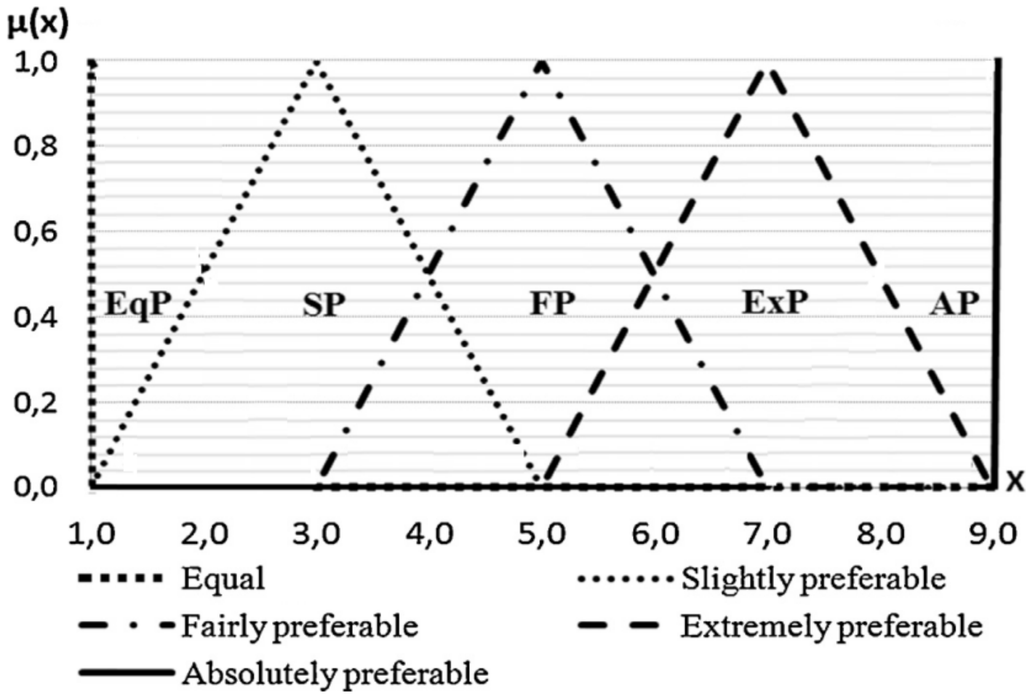


Figure 3.9: Comparative fuzzy membership function of rating alternatives

The following linguistic scales (Fig 3.10) are defined to present the rate of alternatives.

We use the same TFNs and linguistic variables for rating of alternatives in Fuzzy AHP and Fuzzy TOPSIS.

Linguistic scale for ratings of alternatives	
Linguistic terms	Fuzzy triangular number
Equal (EQ)	(1.0, 1.0, 1.0)
Slightly preferable (SP)	(1.0, 3.0, 5.0)
Fairly preferable (FP)	(3.0, 5.0, 7.0)
Extremely preferable (XP)	(5.0, 7.0, 9.0)
Absolutely preferable (AP)	(9.0, 9.0, 9.0)

Figure 3.10: Linguistic scale for ratings of alternatives

3.3.1 (a) FAHP and specialist alternatives

The comparison matrices related to Fuzzy AHP are constructed as determined in tables 3.6-3.11. Tables 3.6, 3.8, 3.10 represent the comparison of alternatives using linguistic variables and tables 3.7, 3.9 and 3.11 show the corresponding triangular fuzzy numbers of linguistic variable in aforementioned tables.

Table 3.6: The comparison of alternatives for C1with linguistic term

C1	A1	A2	A3
A1	EQ	AP	AP
A2	-	EQ	FP
A3	-	-	EQ

Table 3.7: The comparison of alternatives for C1 with TFNs

C1	A1	A2	A3
A1	(1,1,1)	(9,9,9)	(9,9,9)
A2	-	(1,1,1)	(3,5,7)
A3	-	-	(1,1,1)

Table 3.8: The comparison of alternatives for C2 with linguistic term

C1	A2	A1	A3
A2	EQ	AP	AP
A1	-	EQ	SP
A3	-	-	EQ

Table 3.9: The comparison of alternatives for C2 with TFNs

C1	A2	A1	A3
A2	(1,1,1)	(9,9,9)	(9,9,9)
A1	-	(1,1,1)	(1,3,5)
A3	-	-	(1,1,1)

Table 3.10: The comparison of alternatives for C3 with linguistic term

C1	A3	A2	A1
A3	EQ	AP	AP
A2	-	EQ	ExP
A1	-	-	EQ

Table 3.11: The comparison of alternatives for C3 with TFNs

C1	A3	A2	A1
A3	(1,1,1)	(9,9,9)	(9,9,9)
A2	-	(1,1,1)	(5,7,9)
A1	-	-	(1,1,1)

The TFNs is defuzzified based on centroid method (refer section 2.). For example the Defuzzified number of (5, 7, 9) in table 3.11 is calculated as below:

$$Defuzzifiednumber = \frac{5+7+9}{3} = 7.00$$

Tables 3.12, 3.13, 3.14 involve the defuzzified numbers of corresponding pair comparison matrices.

Table 3.12: Defuzzified matrix of alternative rating comparison for criterion C3

C3	A3	A2	A1
A3	1.00	9.00	9.00
A2	-	1.00	7.00
A1	-	-	1.00

In next step we apply classic AHP for weighting alternatives with respect to each criterion. The “AHP Calculation software by CGI” is online calculation software for AHP weights of criteria and alternatives. We set the values of defuzzified matrices as input. The output of online calculation of AHP is the ranking of alternatives in each criterion (Table 3.15).

In this case there are three alternatives, so we inter number 3 to the system as size of pairwise comparison matrix (fig 3.11). There are three criteria as C1, C2 and C3, therefor

Table 3.13: Inputs and outputs of online AHP Calculation software by CGI

Input	Pairwise Comparison Matrix
Input	Size of Pairwise Comparison Matrix
Outputs	Weights (Maximum Eigen Vector)
Outputs	C.I. (Consistency Index) and Eigen Value
Outputs	Pairwise Comparison Matrix
Outputs	Text file of above values (To use other software such as spreadsheets)

we repeat the process of weighting alternatives, three times and each time we use the defuzzified comparison data corresponding to criterion C1, C2 or C3.

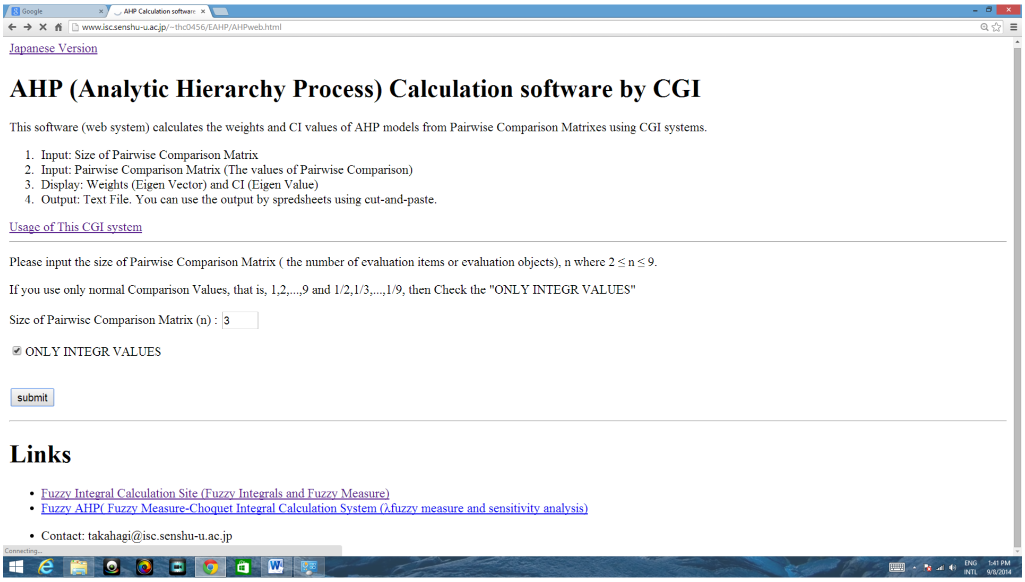


Figure 3.11: Using the number of alternatives as input

Figures 3.12, 3.14 and 3.16 represent the defuzzified pairwise comparison matrices which have been entered to the system for weighting calculation. Figures 3.13, 3.16 and 3.17 involve the weight of alternatives based on tables 3.12, 3.13 and 3.14. The C.I is the rate of inconsistency (refer to section 2.5). In all calculation, this rate is less than 0.5 which shows the significance of results. In software, mistakenly has been written "weghts" instead of "weights" .

Table 3.14: Defuzzified matrix of alternative rating comparison for criterion C2

C2	A2	A1	A3
A2	1.00	9.00	9.00
A1	-	1.00	3.00
A3	-	-	1.00

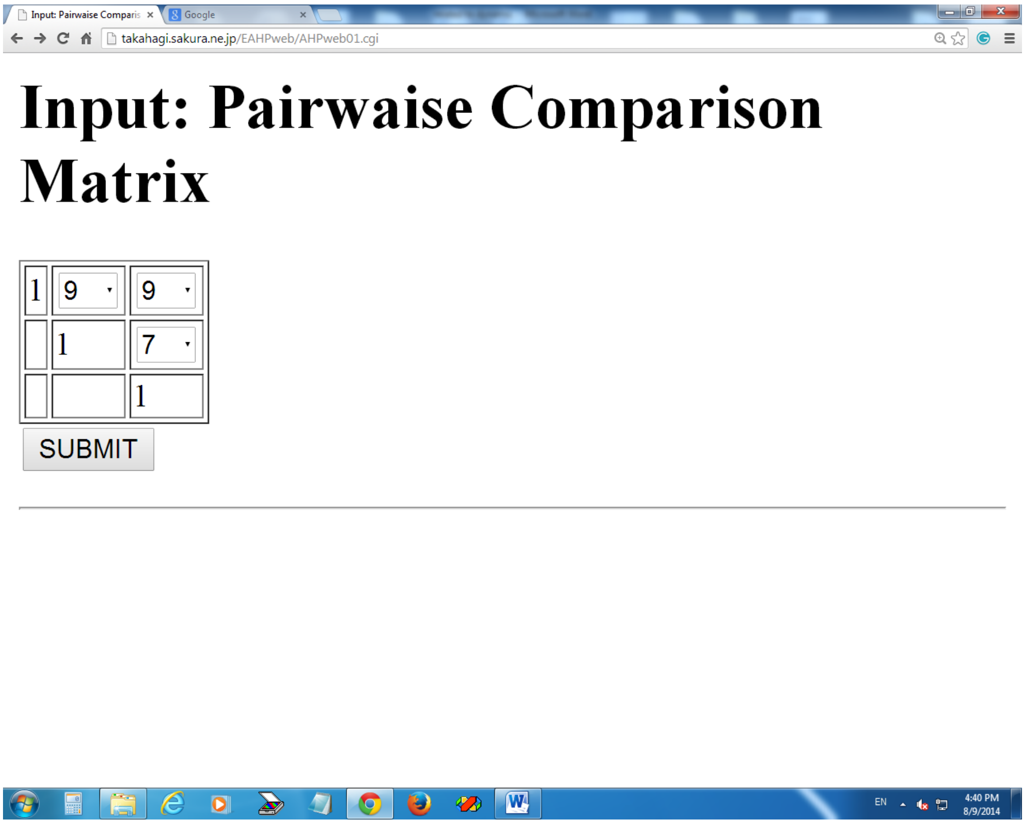


Figure 3.12: Input for weighting of alternatives with respect to C3

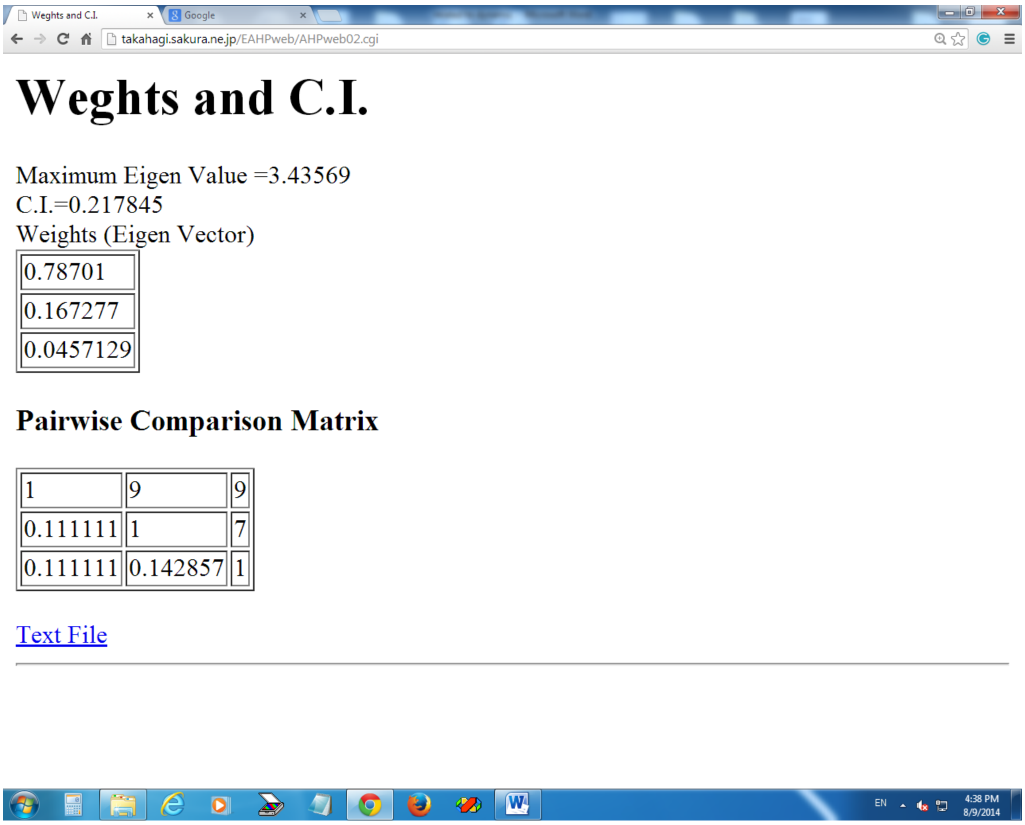


Figure 3.13: Weighting of alternatives with respect to C3

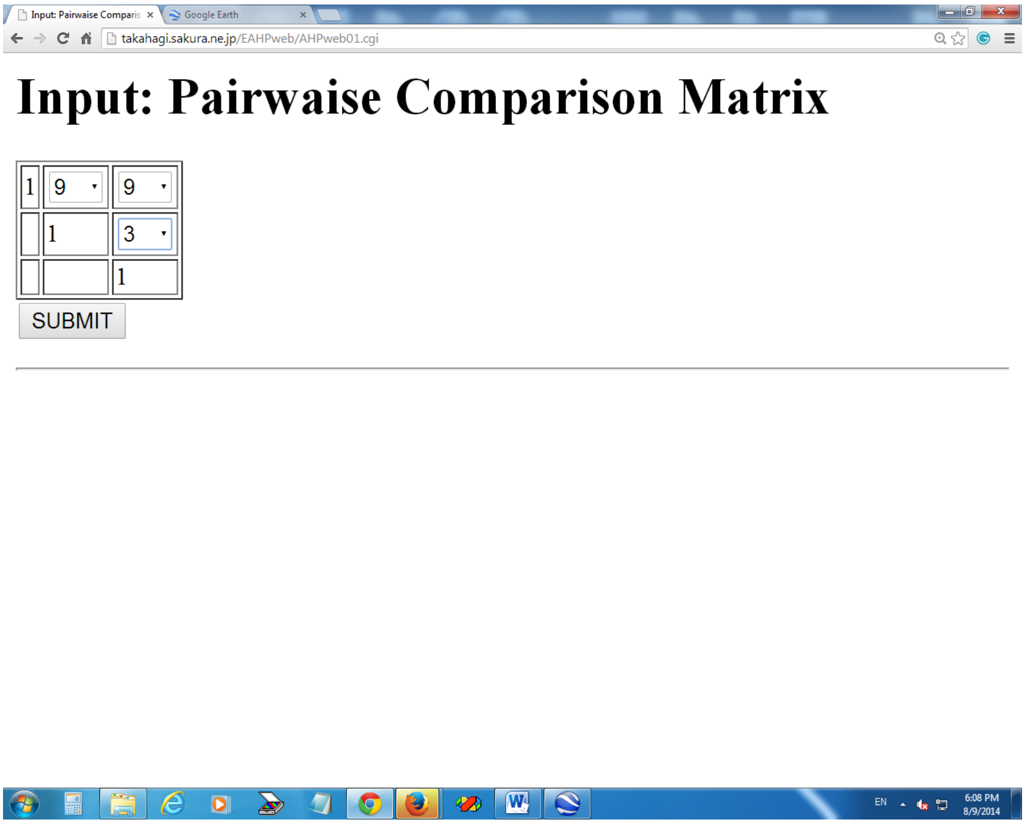


Figure 3.14: Input for weighting of alternatives with respect to C2

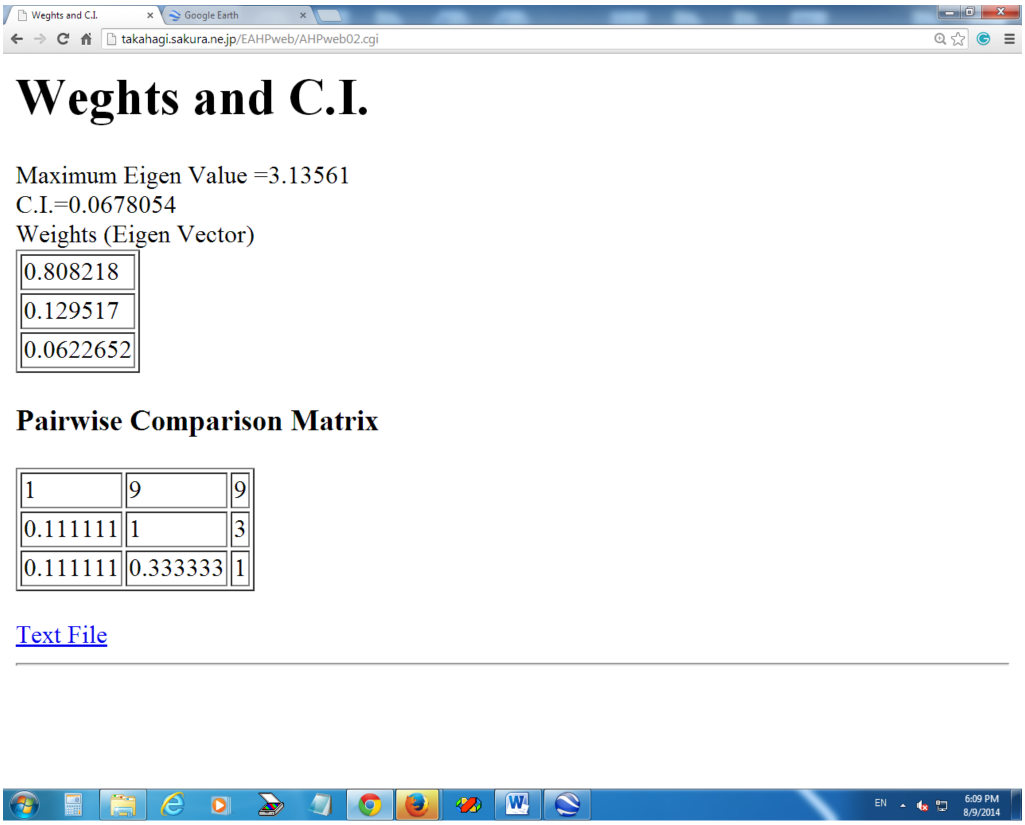


Figure 3.15: Weighting of alternatives with respect to C2

Table 3.15: Defuzzified matrix of alternative rating comparison for criterion C1

C1	A2	A1	A3
A2	1.00	9.00	9.00
A1	-	1.00	5.00
A3	-	-	1.00

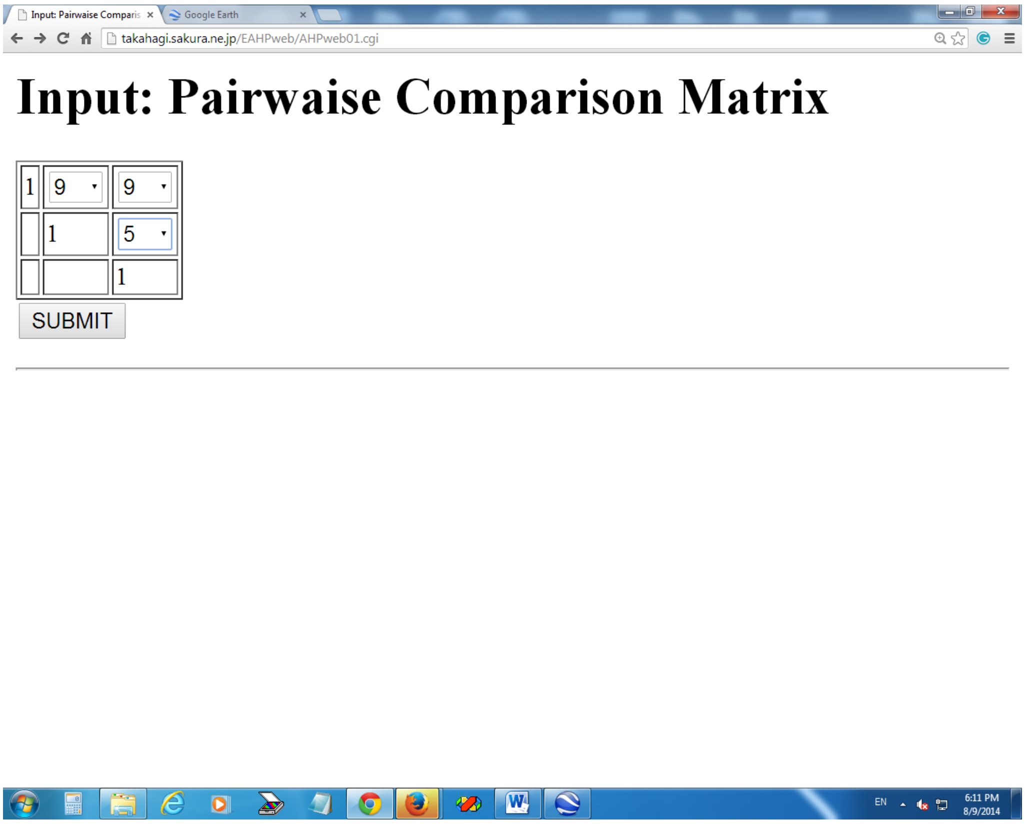
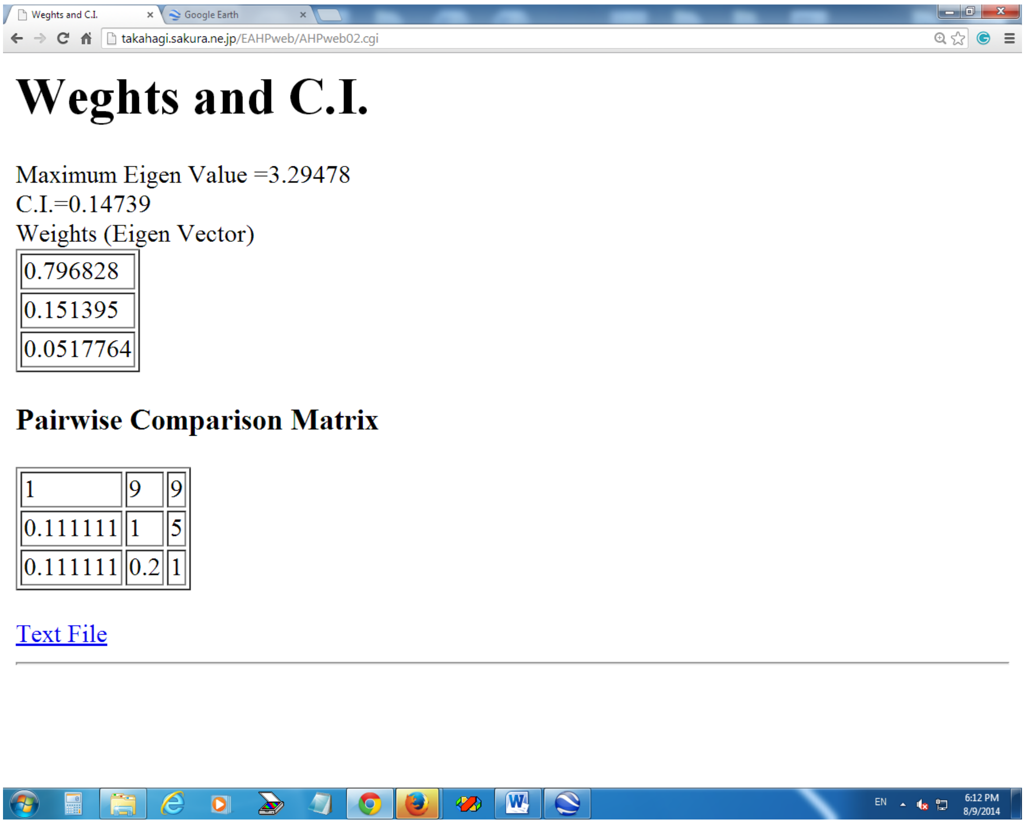


Figure 3.16: Input for weighting of alternatives with respect to C1

There are three criteria, so each alternative got three weights. Therefore, we need to aggregate the weights related to each alternative and calculate the general weights for alternatives. For aggregation of weights we calculate the average of weights corresponding to each alternative. The result of aggregation is also determined in table 3.15. Also the alternatives have been ranked based on the final weights which they have gotten. The alternative with larger weight has rank 1 (table 3.15).

Table 3.16: The obtained weights, their aggregation and corresponding rank

	C1	C2	C3	Final and aggregated weights	Rank
A1	0.796828	0.129517	0.0457129	0.3240193	2
A2	0.151395	0.808218	0.167277	0.37563	1
A3	0.0517764	0.0622652	0.78701	0.30035053	3



Weghts and C.I.

Maximum Eigen Value =3.29478
C.I.=0.14739
Weights (Eigen Vector)

0.796828
0.151395
0.0517764

Pairwise Comparison Matrix

1	9	9
0.111111	1	5
0.111111	0.2	1

Text File

Figure 3.17: Weighting of alternatives with respect to C1

The result shows that, the A2 is the best alternative and A3 is the worst alternative. So, when there is specialist alternative the fuzzy AHP method can deal with weighting of alternatives. Let's repeat the process of evaluation for the same case (specialist alternatives), using fuzzy TOPSIS method to test its performance.

3.3.1 (b) FTOPSIS and specialist alternatives

In this section, first we repeat the experiment of special alternatives using FTOPSIS. We fallow the process of ranking using FTOPSIS which is explained in section 2.3.5.

Table 3.16 shows the importance of alternatives in each criteria. The case is special alternative, so each alternative is only strong in one criteria. For example, A1 is specialist in C1, A2 is specialist in C2 and A3 is specialist in C3. In FTOPSIS, this table, in first step, is filled with linguistic variables (Fig. 3.10).

Positive-ideal A^* and negative ideal A^- solutions is determined using equation (2.16, 2.17). In this case assumed that all the criteria are benefit criteria therefore from equation

Table 3.17: Importance of alternatives in criteria

	C1	C2	C3
A1	AP (9,9,9)	EQ (1,1,1)	EQ (1,1,1)
A2	EQ (1,1,1)	AP (9,9,9)	EQ (1,1,1)
A3	EQ (1,1,1)	EQ (1,1,1)	AP (9,9,9)

(2.16), $\left(max\, v_i \mid i \in I'\right)$ is applied to determine A^*, and from equation (2.17), $\left(min\, v_i \mid i \in I'\right)$ is employed to reach A^-. Table 3.17 shows the considered positive and negative ideal solutions.

Table 3.18: PIS and NIS for evaluation of alternatives

	C1	C2	C3
A^*	(9.00, 9.00, 9.00)	(9.00, 9.00, 9.00)	(9.00, 9.00, 9.00)
A^-	(1.00, 1.00, 1.00)	(1.00, 1.00, 1.00)	(1.00, 1.00, 1.00)

The distance of alternatives from the positive and negative ideal solutions is calculated. The distance of each alternative from A^* and A^- are calculated using equations (2.18) and (2.19) respectively.

Calculation of the distance between A^* and $A1$:

$$D_1^* = \sqrt{\frac{1}{3}\left[(9.00-9.00)^2+(9.00-9.00)^2+(9.00-9.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(9.00-1.00)^2+(9.00-1.00)^2+(9.00-1.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(9.00-1.00)^2+(9.00-1.00)^2+(9.00-1.00)^2\right]}$$

$$= 16.00$$

Also, we have the same distances between A^* with $A2$ and $A3$.

Calculation of the distance between A^- and $A1$:

$$D_1^- = \sqrt{\frac{1}{3}\left[(9.00-1.00)^2+(9.00-1.00)^2+(9.00-1.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(1.00-1.00)^2+(1.00-1.00)^2+(1.00-1.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(1.00-1.00)^2+(1.00-1.00)^2+(1.00-1.00)^2\right]}$$

$$=8.00$$

Also, we have the same distances between A^- with $A2$ and $A3$.

The similarities to ideal solution or satisfaction degree using equation (2.20) is calculated.

Calculation of CC_1^- for A1:

$$CC_1^- = \frac{D_1^-}{D_1^* + D_1^-} = 0.33$$

Calculation of CC_2^- for A2:

$$CC_2^- = \frac{D_2^-}{D_2^* + D_2^-} = 0.33$$

Calculation of CC_3^- for A3:

$$CC_3^- = \frac{D_3^-}{D_3^* + D_3^-} = 0.33$$

Finally, Ranking suppliers according to their CC_j^-, in descending order (Table 3.18).

Table 3.19: Alternative ranking using FTOPSIS

Suppliers	Satisfaction degree CC_j^-	Ranking
A1	0.33	1
A2	0.33	1
A3	0.33	1

The result in table 3.18 shows that the FTOPSIS is not able to produce ranking for specialist alternative and it produce the same rank for all alternatives.

Accordingly, *FTOPSIS method is not suitable for evaluation of specialist alternatives*. The homogeny of alternatives is the similarity of their aptitude. In some DMs, the suppliers as our alternatives are homogeneous that means they have similar degree in their specializations. In opposite, when the aptitude of alternatives related to one criterion is much greater than other criteria then the alternatives consider as specialized or non-homogeneous alternatives. This statement can be defined using the “if-then” rule as:

Definition.6: If $P_{kj} \gg P_{lj}$ then alternatives are non-homogeneous; else alternatives are homogeneous.

Where

- A set of alternative performing of $A = \left[A_j\right]_J$ with regard to criteria $C = [C_i]_n$ defined as $P = \left[\tilde{p}_{ij}\right]_{n\times J}$.
- $i = 1,2,...,n,\ k \in i$
- $l = 1,2,...,n,\ l \neq k.$

In following, we discuss more about the weakness of FTOPSIS method for homogeneous/non-homogeneous alternatives. In general, TOPSIS method composes a positive ideal solution which is ideal alternative/supplier, this alternative is collection of maximum ability of alternatives in each criterion and there is a negative ideal solution as negative alternative/supplier which is collected of minimum ability of alternatives in each criterion. Alternatives' ranking is according the measurement of distance from positive ideal solution and separation from negative ideal solution. In situations with non-homogeneous alternatives, various methods such fuzzy vertex method, Minkowski Distance, Bray Curtis Distance, Canberra Distance and Angular Separation to measure this distance produce different rankings.

In situations with non-homogeneous alternatives, high specialization of alternatives in one criteria causes that they accumulate near maximum points of criteria, and they get very similar distance from PIS and NIS (Fig. 3.18.a).

Therefor applying different methods for distances' measurement lead to get variety alternative ranking where it is difficult and often impossible to select true ranking among them. In opposite situation when decision making has homogeneous alternatives, ideal solution is not far from alternatives and alternatives are distributed in space between positive ideal solution and negative ideal solution (Fig. 3.18.b). In this case alternative ranking by FTOPSIS is reliable.

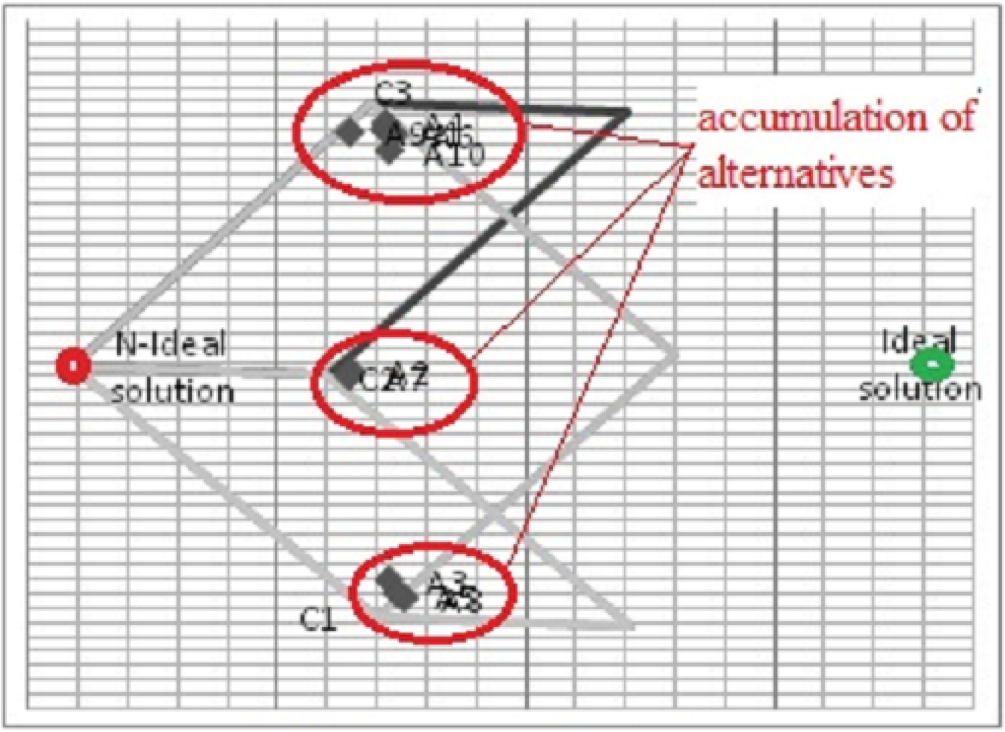
TOPSIS method like other MCDM methods for solving some decision making problems has better performance. The literature shows that the TOPSIS is the best method in changing ranking when a non optimal alternative arrive, hence in DM with high probability of re-ranking, result of TOPSIS is more reliable Fuzzy TOPSIS is not suitable for some DM problems such complicated problems as well as DM problems with specialized alternatives. The proposed method manages effective of TOPSIS on the final ranking according its suitability for related problem.

3.3.2 Environment of decision making in SES

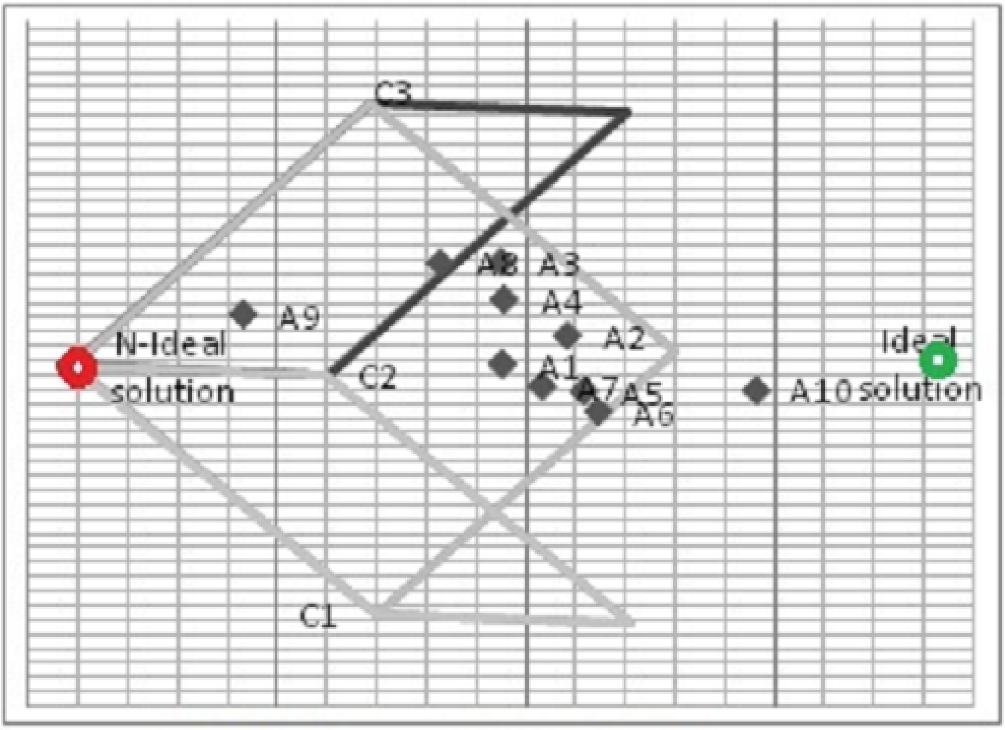
The environment of decision making has three main components including 1) situation of decision makers, 2) situation of criteria and 3) situation of alternatives (refer 2.2.1).

In first component, the situation of decision makers can be different in decision makings based on *inconsistency*. For instance, in some decisions the experts have many different ideas about a decision, so the inconsistency is high (refer 2.3.4).

In second component, the situation of criteria can be different indecision making based on number of criteria and sub criteria *(C-population)* (refer 2.3.4).



a. Homogeneous alternatives



b. Non-homogeneous alternatives

Figure 3.18: homogeneous alternatives are located in similar distances from PIS and NIS and non-homogeneous alternatives are distributed between PIS and NIS

In third component, the situation of alternatives can be different in decision makings based on number of alternatives, frequent change of alternatives and specialization of alternatives. In order we present them as *A-population, Re-ranking and Homogeny of alternatives* (refer 2.3.5). Here, we list the elements of these situations which are not static in different decision makings:

- Homogeny of alternatives,
- Re-ranking,
- Inconsistency,
- C-population,
- A-population.

Considering to the abilities and attributes of FAHP and FTOPSIS(section 2.3), the efficiency of FAHP and FTOPSIS is different in situations. For example, when the re-ranking is high then using FTOPSIS method is more efficient than FAHP.

We assign two variables to show the effectiveness ratio of FAHP and FTOPSIS in different situations. We nominate these variables as *"FAHP impact"* and *"FTOPSIS impact"*. These variables may used to make decision about selecting the suitable method (FAHP or FTOPSIS). In following sections we explain the situations and their relation with FAHP impact and FTOPSIS impact.

3.3.2 (a) Homogeny of alternatives

As we discussed in section 2.2.1, when the alternatives are specialized, then the ideal solution is very far from the alternatives and the alternatives have similar distance from ideal solution. Therefore, we cannot get correct ranking according distance. When the criteria are equiponderant, the problem is more. So in this condition using FAHP with high impact is preferred (table 3.19). On opposite condition when decision making has homogeneous alternatives, the alternatives are distributed and in this case alternative ranking by FTOPSIS is more reliable.

Table 3.20: Increasing/decreasing FAHP impact with the decision making conditions

AHP impact	**FTOPSIS impact**	Re-ranking	Population	Homogeny	Inconsistency
↑	↓	↓	↓	↑	↓
↓	↑	↑	↑	↓	↑

3.3.2 (b) Re-ranking

Sometimes decision making does not have fixed alternatives and even after ranking may need to enter new alternative and repeat evaluation and ranking of them. TOPSIS is the best method addressing rank reversal issue that is the change in the ranking of the alternatives when a new alternative is introduced (refer 2.3.5). Therefore, when the *probability of re-ranking* is high, FTOPSIS method has more reliable result and it is preferred. In this situation FAHP impact should be decreased (Table 3.19). Probability of re-ranking is determined based on experts' opinions.

3.3.2 (c) Inconsistency

AHP method composes pairwise comparison matrices for all alternatives and criteria. Normally, when we have qualitative criteria, the data of these matrices should be collected through interviews and based on experts' opinions. Sometime there are some problems regarding interview with experts such as the experts do not interest to answer questions carefully, or there are numerous experts as decision makers. In this conditions, *probability of inconsistency* in the answers is high. In TOPSIS we do not have pairwise comparison, therefore in such conditions using FTOPSIS method is preferred and FAHP impact should be decreased (Table 3.19). Probability of inconsistency is also determined based on the opinion of decision maker.

3.3.2 (d) Population

Population means number of alternative and criteria in decision making. Through AHP, the decision maker is only asked to give judgments about either the relative importance of one criterion against another or its preference of one alternative on one criterion against another.

However, when the number of alternatives and criteria grows, the pairwise comparison process becomes cumbersome, and the risk of inconsistencies grows (Bottani and Rizzi 2006).

This condition effects on probability of inconsistency. When the population is high the probability of inconsistency also is high. Moreover, using AHP for problems with many criteria and alternatives is not suitable (Bottani and Rizzi 2006). Therefore, if population (number of alternative and criteria) is high then the effectiveness of FAHP should be decreased (Table 3.19).

The population divided to separate condition as A-population and C-population. The A-population indicates number of alternatives and C-population indicates number of criteria.

We evaluate and aggregate the situations using FIS to determine FTPSIS and FAHP impact. However, the input of FIS is based on expert team judgments. In the next section, we describe the developed FIS.

3.4 Summary

We analyzed 207 papers involving AI and MCDM topic. The required operations for SES are evaluation, ranking and selection (ERS). The most suitable AI and MCDM methods which can fulfill the SES requirements are FTs, AHP and TOPSIS methods. The best hybridization type of FTs with AHP and TOPSIS is integration of FTs with AHP and TOPSIS. After extensive reviews and analysis in previous sections we concluded that

Fuzzy AHP (FAHP) and Fuzzy TOPSIS (FTOPSIS) are candidate methods to apply for supplier management. However, still managers are not satisfied with the performance of these methods which is through their limitations and challenges in produce a high accurate results. Therefore, technically we analyzed these methods to discover their weaknesses and the way to improve them.

The decision methods are effected by environment changes and for different cases the suited decision method should be employed. The accuracy of a decision making model is high since it works based on the situations.

In a decision making with homogeneous alternatives, ideal solution is not far from alternatives and alternatives are distributed in space between positive ideal solution and negative ideal solution. In this case alternative ranking by FTOPSIS is reliable.

FAHP and FTOPSIS do not working well in all situations. Therefore, individually using of FAHP and FTOPSIS reduces the accuracy. Integrating these methods caused to switch between methods when in a specific situation one of them has limitation. This technique may increase the accuracy of SES.

CHAPTER 4

FUZZY DYNAMIC HYBRID MCDM (FDHM) METHOD

4.1 Introduction

The fuzzification, dynamization and hybridization operations overcome the limitations of current methods (fig 4.1). We propose Fuzzy Dynamic Hybrid MCDM (FDHM) method that involves these operations. Implementation of all these operation together in proposed method makes increases the accuracy of supplier evaluation and selection.

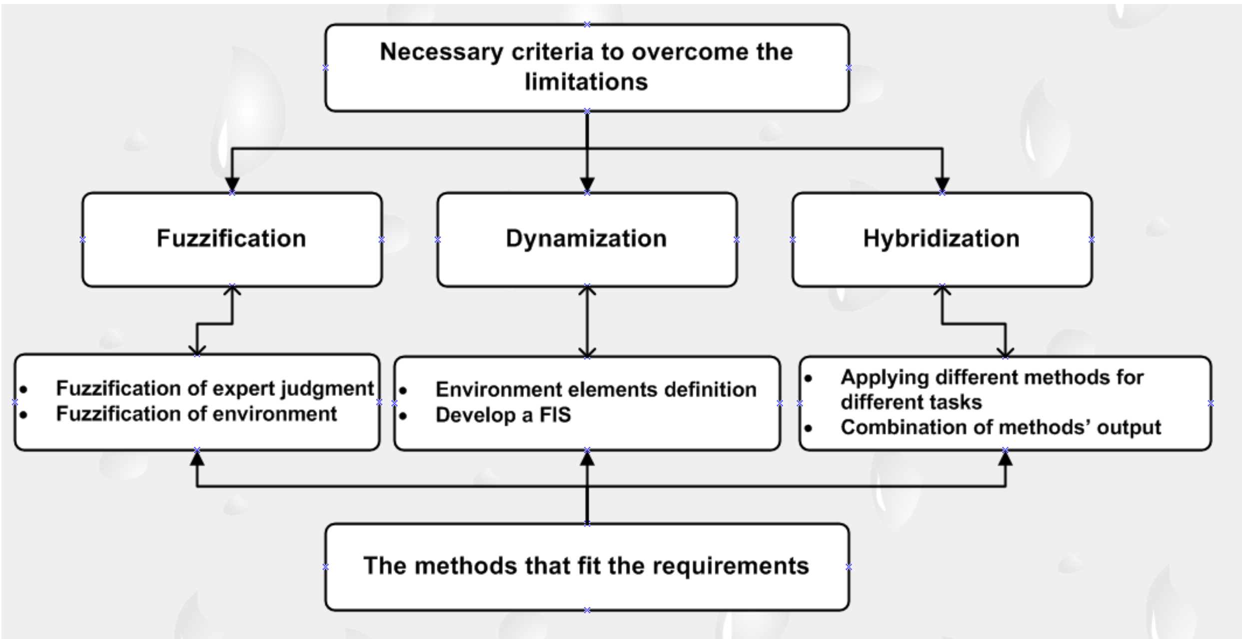


Figure 4.1: Limitations addressing by FDHM

The methods are applied to fit the requirements of considered criteria (Fig 4.1). In the *dynamization*, the DM environment is defined to study the manner of methods on that (section 3.3.1). Based on this environment the proper method or methods are selected for evaluation of alternatives. Based on environment the effectiveness of methods is different. In some cases FAHP can produce high accurate results and in some cases FTOPSIS. Hence, the dynamic method selects one of these methods or combination of both based on the DM situations. The limitation of FAHP and FTOPSIS in different environment is addressed by the dynamically selection of one of candidate methods for alternative evaluation. FIS is then used to evaluate the DM situations and determines the impact of FAHP and FTOPSIS based on situation of alternatives, criteria and decision makers.

For the *Hybridization*, we integrate AHP and TOPSIS in order to maximise the benefits from their respective strengths, and minimise their respective weaknesses. FAHP is used to deal with criteria weighting, while FTOPSIS deals with alternative ranking, depending on the situations. When the FIS determines the combination of methods as the proper evaluation method then, the output of methods are combined based on their impact factors.

In DM fuzzification, fuzzy set theory is employed to handle vagueness and subjectivity of linguistic variables that are produced by decision makers in assessing criteria, alternatives and DM situations. In chapter 2 we discussed about the limitations of classic AHP and TOPSIS to overcome the uncertainty. Therefore we consider the fuzzification criteria to overcome this limitation. The TFN is identified as the best type of MFs to describe the linguistic variables for MADM. Also, FIS is developed based on fuzzy MFs and fuzzy “if-then” rules to overcome the uncertainty in measuring the environment elements. In FIS, for each situation the appropriate MF is considered based on the aspects involved in the considered situation.

4.2 FDHM Process

FDHM is an extended MCDM method for selection of the best alternative in MADMs. Figure 4.2 shows the process of FDHM.

The starting point of this method is that a company needs to make decision and select the best alternative for a purpose.

The team of decision makers in company is identified and has been asked to fill up the

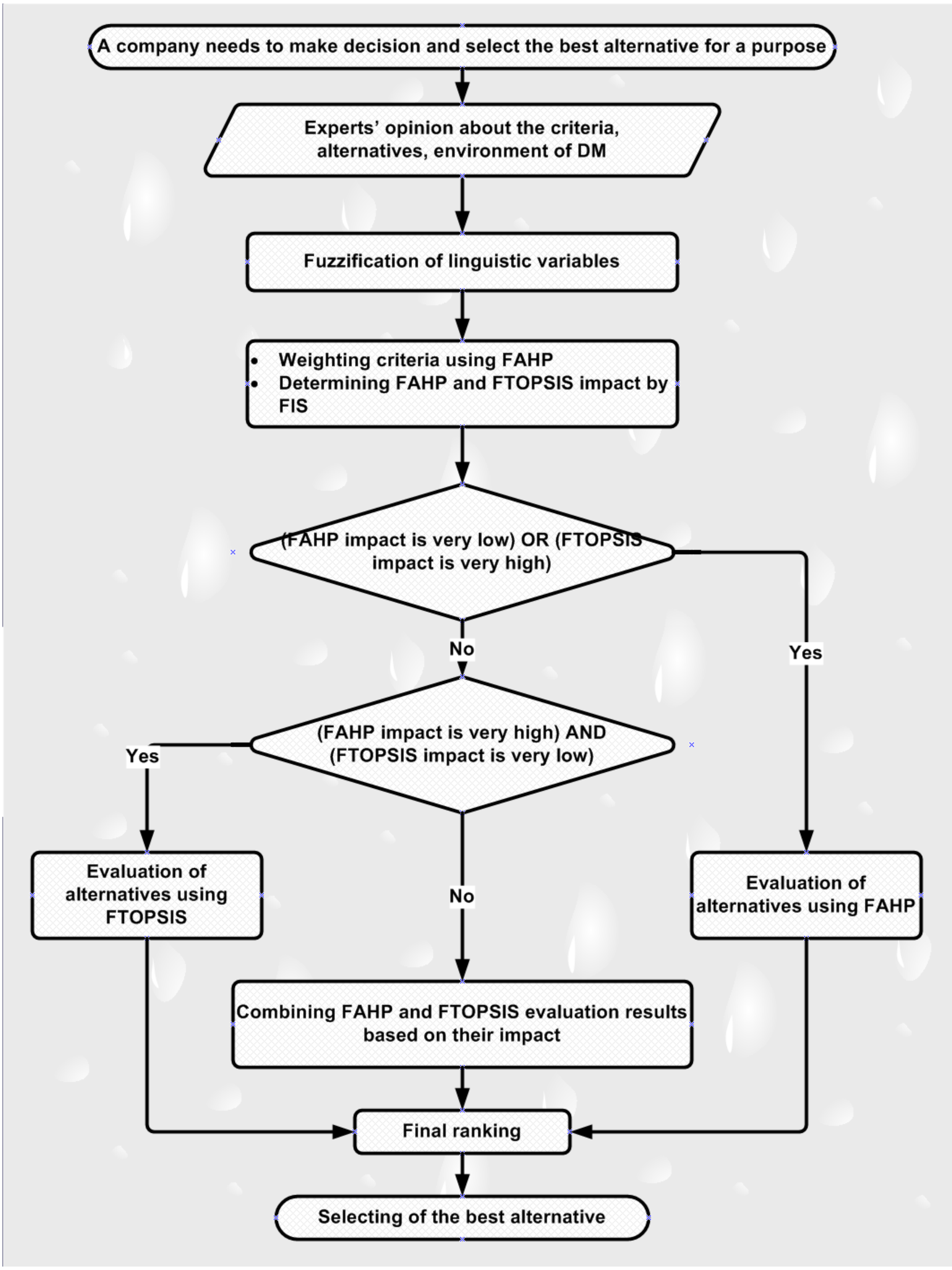


Figure 4.2: FDHM process

prepared questioner. The questioner is a set of questions related to (i)criteria/alternatives and (ii) environment of DM. They have been asked to answer the questioner by linguistic variables. Therefore, the opinion of experts is received as fuzzy variables.

The data is fuzzified and difuzzified to use as input of methods. Some parts of the data, which is related to criteria, are used by the FAHP method for weighting purposes, while other parts of the data, which is related to the decision environment, is used by FIS to determine the proper strategy to evaluate the alternatives.

The proposed fuzzy AHP method in this section constructs the fuzzy pairwise comparison matrices based on the opinions of a team of experts. Then, the data will be aggregated and defuzzify the fuzzy values for use in AHP calculations. The output of this method is the weighted criteria.

Based on the environment' data the FIS determines the FAHP Impact (AHPI) and FTOPSIS Impact (TOPSISI). In this step, the method chooses a suitable way for evaluation of alternatives based on obtained method' impacts. The determined method evaluates and ranks the alternatives. Finally, the method select the high rank alternative as the best alternative.

4.3 Data Collection

The decision makers' opinions are the most needed data for FDHM. Often, the decision makers are managers and experts in their companies. We will, from now, proceed to use these terms interchangeably.

The decisions in companies are very important and mostly they handled by a team of decision makers. So, the data is supposed to be collected from a team and not only one expert.

The FDHM needs the data from decision makers to handle four operations as:

i) Determination of criteria

ii) Determination of FAHPI and FTOPSISI

iii) Comparison of criteria

iv) Comparison of alternatives

A questioner is prepared to collect the needed information for above operations (Appendix E). The FDHM is designed for all MADMs. Therefore, the questioner is different in different MADMs and the list of criteria in part A of questioner is based on the considered MADM.

The FDHM is a dynamic method, therefor the questioner also is different based on the environment of decision making. The first two parts of questioner (Parts A, B) are related to collect the primary data. These data are collected to set as the input of FIS. The secondary data involve the necessary data for evaluation of criteria and alternatives. The last two parts of questioner (Parts C, D) are related to these data.

4.3.1 Primary Data

The primary data are collected to address the determination of criteria and the determination of FAHPI and FTOPSISI.

The part A is designed to collect the data for determination of criteria. The part B is designed to fit the requirements of FIS for determination of methods' impact.

Part A proposes a list of criteria (related to decision making) to decision makers, such as experts and managers. The decision makers select the criteria that they are taking into account for the DM. Even if a criterion is not a major one, the selection should still be made by a decision maker. It should also be pointed out that the list of criteria in this section differs from decision-makings.

It is necessary to consider all the determined criteria by the decision makers, which prompts us to average their respective answers. For instance, although a criterion is selected by only one decision maker and not by others, we still take this criterion into account in the FDHM.

The questions related to the environment of decision making (Refer to section 3.3) are placed in **Part B**. The expert team are requested to fill questioners regarding evaluation of pure fuzzy inputs as probability of inconsistency, Re-ranking and percentage of alternatives homogeneous. The decision makers have been asked to determine a point in rang of [0 100] or expressed their idea as linguistic variables. The expressed numbers of these section directly enter to FIS, then the FIS generates the AHPI and TOPSISI. The AHPI and TOPSISI determine the method of alternative evaluation.

4.3.2 Secondary data

The secondary data are collected to address the comparison of criteria and the comparison of alternatives.

Part C proposes a comparison table of criteria to decision makers. This table is based on the criteria which is determined by decision makers in part A. The experts compare the determined criteria with each other. We asked them to express their ideas through the linguistic terms.

Therefore, we provide more flexibility for experts in answer the question as well as accuracy in analyzing the data.

The collected data from this section uses for weighting of the criteria.

Part D involve questions related to comparison of alternatives. The collected data from part B is used to determine the method of alternative evaluation. Therefore, questions in this part is depended to determined method. We have two type of questions is form of tables as:

i) The pairwise comparison matrices for comparison of alternatives in each criterion is proposed related to FAHP method.

ii) The preference table of alternatives in criteria related to FTOPSIS method.

The questioner provided in appendix E is presenting the second type of questions.

The data collected from this part is used for considered evaluation method.

W assumed that the experts have the same weights, so we employed the method of average value to aggregate the fuzzy judgment values of different experts regarding the same evaluation of criteria, situation or alternatives.

4.4 Criteria management

The management of criteria includes determination an weighting of criteria. The criteria of DMs plays an effective role in evaluation of the DM alternatives. The different decisions have different criteria. The determination of criteria in DMs depend to many conditions such as:

i) Policy of company,

ii) Policy of experts,

iii) Subject of DM,

iv) Importance of DM.

Often, the evaluation methods works based on the constant list of criteria in different DMs, which is unsuitable as the DM criteria depends on similar aforementioned conditions. The weighting of criteria is also depends to the experts' judgment. The judgments about the weighting of criteria is based on mentioned conditions.

4.4.1 Criteria determination

We prepared an initial list of criteria (table 4.1). This list is inspired by the list of criteria proposed by Swift in section 2.2.1.

The decision makers select the important criteria from the initial list. The important criteria are all the considered criteria in DM even with small consideration.

Table 4.1: Initial list of criteria

Number	Criteria
	Product
1	Ease of operation
2	Impact on energy utilization
3	Ease of maintenance design
4	Amount of pre-purchase information
5	Contribution to productivity
6	Cost of service contract
	Availability
7	Breadth of product line
8	Geographic proximity
9	Vendor's image
10	Financial capacity
11	Quality Assurance
	Dependability
12	On time delivery
13	Technical abilities
14	Reliability of product
15	Service response time
	Experience
16	Preferences established by users
17	Prior experience with vendors
18	Reputation of suppliers
	Price
19	Price/performance
20	Low price
21	Total cost of product

The determined criteria is aggregated to obtain the complete list of criteria. Therefore, if a criterion is selected only by one decision maker and it is not considered by others then also we consider it for DM.

When K is the number of decision makers that they participated in deta collection, and the $[exc]_k$ is the set of criteria determined by decision maker k where $k = 1, 2, ..., K$. Then the following equation determines the final set of criteria $[FC]$ as:

$$[FC] = [exc]_1 \cap [exc]_2 \cap \ldots \cap [exc]_K \tag{4.1}$$

4.4.2 Criteria weighting

The AHP method is employed for weighting of criteria due to following reasons:

- The AHP method composes hierarchy tree for criteria and sub criteria. Therefore, it is able to address complex DM even with multi level of sub criteria.

- The TOPSIS method does not use hierarchy process to analyze complex decision making and for weighting does not distinguish between criteria and sub criteria. Therefore, TOPSIS is not suitable for weighting of criteria.

The AHP is extended with fuzzy set theory to overcome the uncertainty. The classic AHP method does not consider to the uncertainty and subjectivity of human judgments. So,uncertainty has a great effect on AHP results.

The fuzzification of AHP method has not a constant formula. This fuzzification is should be suited to decision analysis method(refer section 2. 3. 4). The AHP is fuzzified in the stage of input data and comparison matrices.

The decision makers compare the determined criteria with each other. We asked them to express their ideas through linguistic terms such: ‘‘Perfect,” ‘‘Absolute,” ‘‘Very good,” ‘‘Fairly good,” ‘‘Good,” ‘‘Preferable,” ‘‘Not Bad,” ‘‘Weak advantage” and ‘‘Equal” with respect to a fuzzy nine level scale.

The data that are expressed by linguistic variables includes ambiguous data(Refer to section 2. 3). Therefore, we use fuzzy set theory to fuzzify the linguistic variables. The data as triangular fuzzy numbers apply in $E\tilde{C}M$ pairwise comparison matrices.

The computational technique for fuzzification of linguistic terms is shown in table 4. 2.

Next, the answers of the experts' team is aggregated by the following equation.

$$C\tilde{W}_{ij} = \frac{\sum_{k=1}^{K} ec\tilde{m}_{kij}}{K} \tag{4.2}$$

Where

Table 4.2: Membership function of linguistic scale

Fuzzy numbers	Linguistic	Scale of fuzzy number
9	Perfect	(8, 9, 10)
8	Absolute	(7, 8, 9)
7	Very good	(6, 7, 8)
6	Fairly good	(5, 6, 7)
5	Good	(4, 5, 6)
4	Preferable	(3, 4, 5)
3	Not bad	(2, 3, 4)
2	Week advantage	(1, 2, 3)
1	Equal	(1, 1, 1)

- $k = 1,2,...,K$, $i = 1,2,...,N$ and $j = 1,2,...,N$; When K is the number of experts and N is the number of criteria.

- $\tilde{CW} = \left[\tilde{cw}_{ij}\right]_{n\times n}$ is the fuzzy pairwise comparison matrix and $\tilde{cw}_{ij}$ is the importance of the criterion C_i over criterionC_j.

- $\tilde{ECM} = \left[\tilde{ecm}_{kij}\right]_{K\times N\times N}$ is the fuzzy Expert Comparison Matrix and $\tilde{ecm}_{kij}$ is a TFN which shows the importance of the criterion C_i over criterionC_j Obtained from the expert k.

The $\tilde{CW}$ is a pairwise comparison matrix involving the fuzzy values which can not be involved in AHP computations. Therefore, the values of this matrix is defuzzified using the Median method (Refer to 3.2.3) and convert it to a pairwise comparison matrix (CW) with crisp values. The the following steps of AHP method are carried out to obtain the weight of criteria (Refer to 3.2.4) .

4.5 Fuzzy Inference System (FIS)

The FAHP method is used for weighting of the criteria that cause to reduce the complexity of DM. However, the continue of method for alternatives' evaluation with FAHP is not effected in all the time. Sometimes using FAHP for evaluation of alternatives increases the executing time of DM. Also using FTOPSIS is not proper in some conditions.(Refer section 3. 3. 2)

The FDHM dynamically determines the suitable method for continuing of the decision making process to increase the accuracy and skip the complex computations.

The determination of alternative evaluation method is based on two factors:

i) Changes of decision making environment,

ii) The attributes of methods in these changes.

A Fuzzy Inference System (FIS) is designed and developed in "MATLAB R2011b" to determine the Alternative Evaluation Method (AEM). The FIS fuzzifies and aggregates the environment changes and generate FTPSISI and FAHPI. However, the result of FIS is based on the judgments of expert team regarding environment.

4.5.1 Fuzzification of environment elements

The expert team are requested to fill questioners regarding evaluation of pure fuzzy inputs as probability of inconsistency, Re-ranking and percentage of alternatives homogeneous. The experts have been asked to choose on of following way to answer questions:

- Determine a point in rang of [0 100] or expressed their idea as linguistic variables. If the expert follows this way, the expressed numbers of these section directly enter to FIS.
- Answer the question from adopted linguistic terms from table 4.2, including “very high”, “high”, “Moderate”, “low” and “very low” to express their opinions. We replaced these linguistic values with their corresponding TFNs based on table 4.3.

The obtained fuzzy values of environment’ elements are defuzzified using Median diffuzification method (section 2.3.3). The experts have the same weights, so we employ the method of average value to aggregate the answers of different experts regarding the same evaluation of criteria, environment and alternatives. The obtained numbers related to environment’ elements are employed as input for FIS.

Table 4.3: Linguistic values for evaluation of inconsistency, re-ranking and homogeny

Linguistic variables	Triangular fuzzy number
Very high	$(0,1,3)$
High	$(1,3,5)$
Medium	$(3,5,7)$
Low	$(5,7,9)$
Very low	$(7,9,10)$

4.5.2 Input/output membership functions

The input/output of FIS is determined and the proper MFs with regard to type of elements and linguistic variables are defined. Figure 4.3 shows the design of FIS. The FIS involves five inputs and two outputs as:

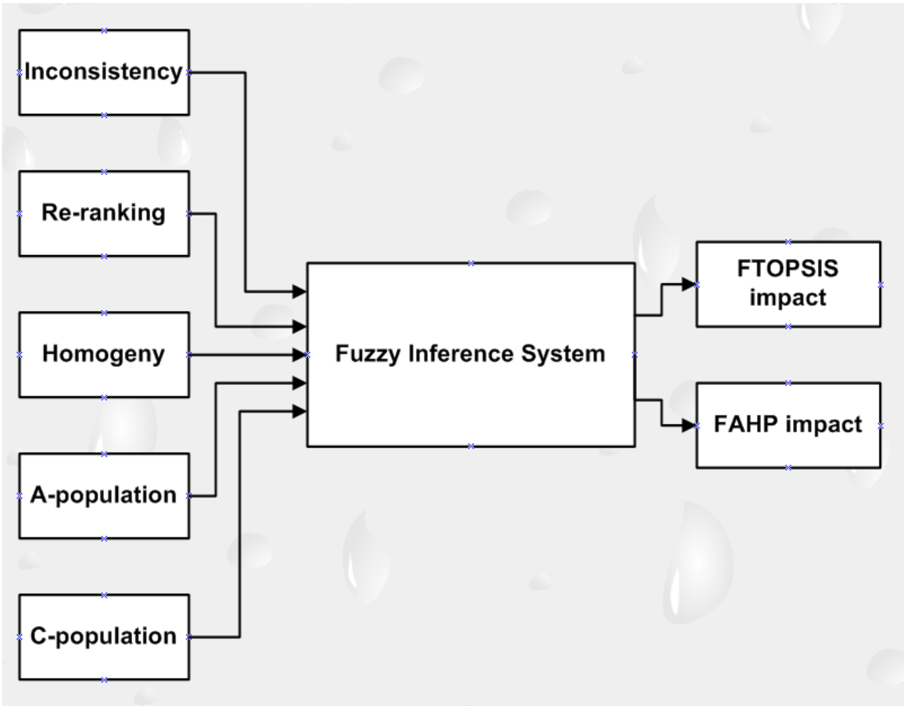


Figure 4.3: FIS design

Input i) Re-ranking

ii) Inconsistency

iii) Homogeny

iv) A-population

v) C-population

Output   i) FAHPI

ii) FTOPSISI

The FIS has the following specifications:

- Type: Multiple Input Single Output (MISO),
- Inference method: Mamdani,
- Operators: standard (Zadeh's method),
- Defuzzification method: Center Of Area (COA).

In FIS, numbers and intervals of membership functions in linguistic terms are defined based on expert judgment. Figs. 4.4 and 4.5 illustrate the membership functions related to input and output of FIS.

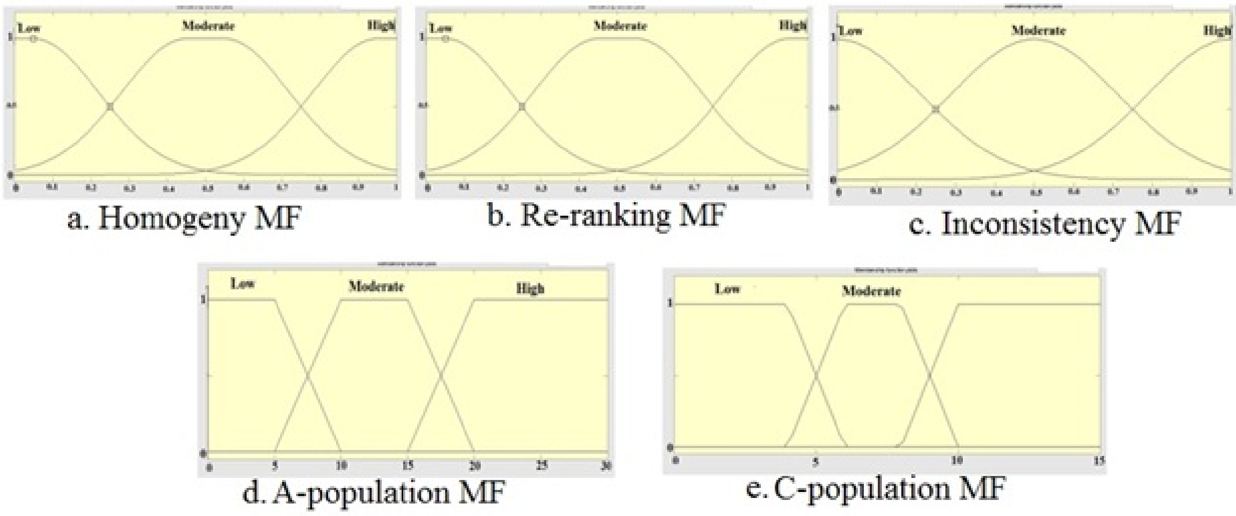


Figure 4.4: Input membership functions of FIS

The reasons to defined these MFs for inputs/outputs are as below:

- Inconsistency, homogenous and re-ranking are *pure fuzzy inputs* which are evaluated completely based on experts' opinion and through fuzzy variables. Therefore, we select Gaussian membership functions to obtain accuracy in defuzziffication values of these situations.

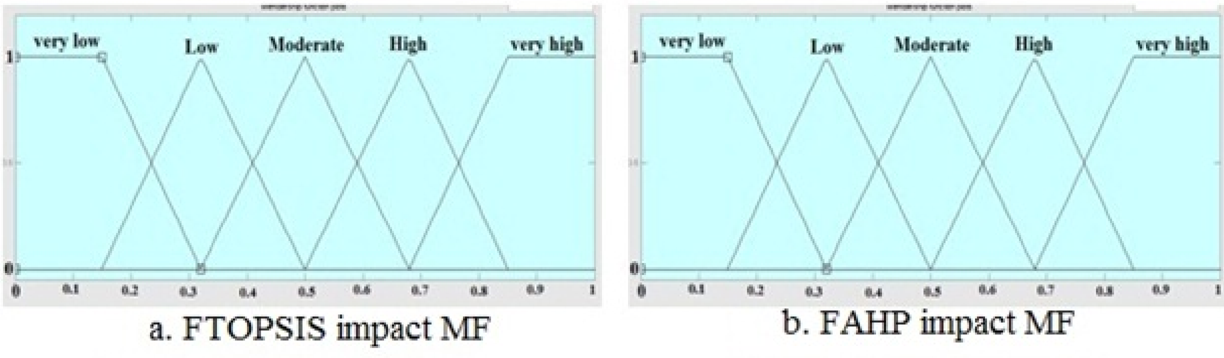


Figure 4.5: The output membership functions of FIS

Three simple Gaussian membership functions are defined for evaluation of inconsistency situation as:

- low [0.2123 0],
- moderate [0.2123 0.5],
- high [0.2123 1] (see Fig. 4.4. c),

Three Gaussian2 membership functions are defined for homogenous and re-ranking as:

- low [0.1699 -0.05 0.1699 0.05],
- moderate [0.1699 0.45 0.1699 0.55],
- high [0.1699 0.95 0.1699 1.05] (see Fig. 4.4. a, b) .

- A-population and C-population are fuzzy inputs which are evaluated based on experts' opinion and their numerical values. A-Population is number of alternative and C-population is number criteria which experts' opinions are used to define their membership functions.

  Three trapezoidal membership functions are defined for A-populationas situation as:

  - low [0 0 5 10],

- moderate [5 10 15 20],
- high [15 20 Inf Inf] (see Fig. 4.4. d).

Three trapezoidal membership functions are defined for C-population as:

- low [0 0 4 6],
- moderate [4 6 8 10],
- high [8 10 Inf Inf] (see Fig. 4.4. e).

4.5.3 Fuzzy If-then rules

A set of rules are defined for FIS to inference the impacts numbers based on these rules. The rules are designed according the attributes of methods in different conditions. The DM environments' elements are the facts in FIS which are changeable in different DMs. However, the determined rules are constant for any environments and conditions.

Rules of the FIS are listed in table 4. 4. The components of the rules are based on intervals of membership functions in Fig. 4.4 and 4.5. The "if" parts of the rules are based on input membership functions shown in Fig. 4.4 and, the then-parts of rules are according specifications of FAHP and FTOPSIS methods.

The population is a factor to determine inconsistency. Therefore if inconsistency is high or if it is low then the population situation will not considered.

The outputs of FIS, in order are influenced by inconsistency, homogeny, Re-ranking, A-population and C-population.

These rules determine the mechanism of environment' effectiveness on methods' impact. When the FIS receives the inputs, the inputs fill the "if" parts of rules and the "then" parts be aggregated and defuzzified to obtain the final FAHPI and FTOPSISI. The view some of these rules is shown in figure 4.6.

Table 4.4: Set of FIS rules. L (low), M (moderate), H (high), VH (very high), VL (very low), N (non)

Operators	If	and	and	and	and	then	and	
Number	RR	HO	IC	A-pop	C-pop	FAHP impact	FTOPSIS impact	Weight
1	M	H	H	N	N	VL	VH	1
2	M	H	L	N	N	M	H	1
3	M	H	M	H	H	L	VH	1
4	M	L	H	N	N	VL	H	1
5	M	L	L	N	N	H	L	1
6	M	L	M	H	L	L	M	1
7	M	M	H	N	N	VL	H	1
8	M	M	L	N	N	H	M	1
9	M	M	M	H	M	L	H	1
10	L	H	H	N	N	VL	V	1
11	L	H	L	N	N	H	M	1
12	L	H	M	L	H	L	H	1
13	L	L	H	N	N	VL	M	1
14	L	L	L	N	N	VH	VL	1
15	L	L	M	L	L	H	L	1
16	L	M	H	N	N	VL	H	1
17	L	M	L	N	N	H	L	1
18	L	M	M	L	M	M	H	1
19	H	H	H	N	N	VL	VH	1
20	H	H	L	N	N	H	H	1
21	H	H	M	M	H	VL	VH	1
22	H	L	H	N	N	VL	VH	1
23	H	L	L	N	N	H	VL	1
24	H	L	M	M	L	M	M	1
25	H	M	H	N	N	VL	VH	1
26	H	M	L	N	N	H	VL	1
27	H	M	M	M	M	M	H	1

Figure 4.7 shows the effectiveness of "Homogeny" and "Re-ranking" on FTOPSIS imapact. Increasing homogeny and re-ranking in DM causes to increase the FTOPSIS impact. This plot shows that the implementation of rules in FIS, is according to methods' attributes.

Figure 4.8 shows the effectiveness of "Homogeny" and "Inconsistency" on FTOPSIS imapact. Increasing homogeny and inconsistency in DM causes to increase the FTOPSIS impact. This plot shows that the implementation of rules in FIS is according to methods' attributes.

Figure 4.9 shows the effectiveness of "Inconsistency" and "Re-ranking" on FTOPSIS

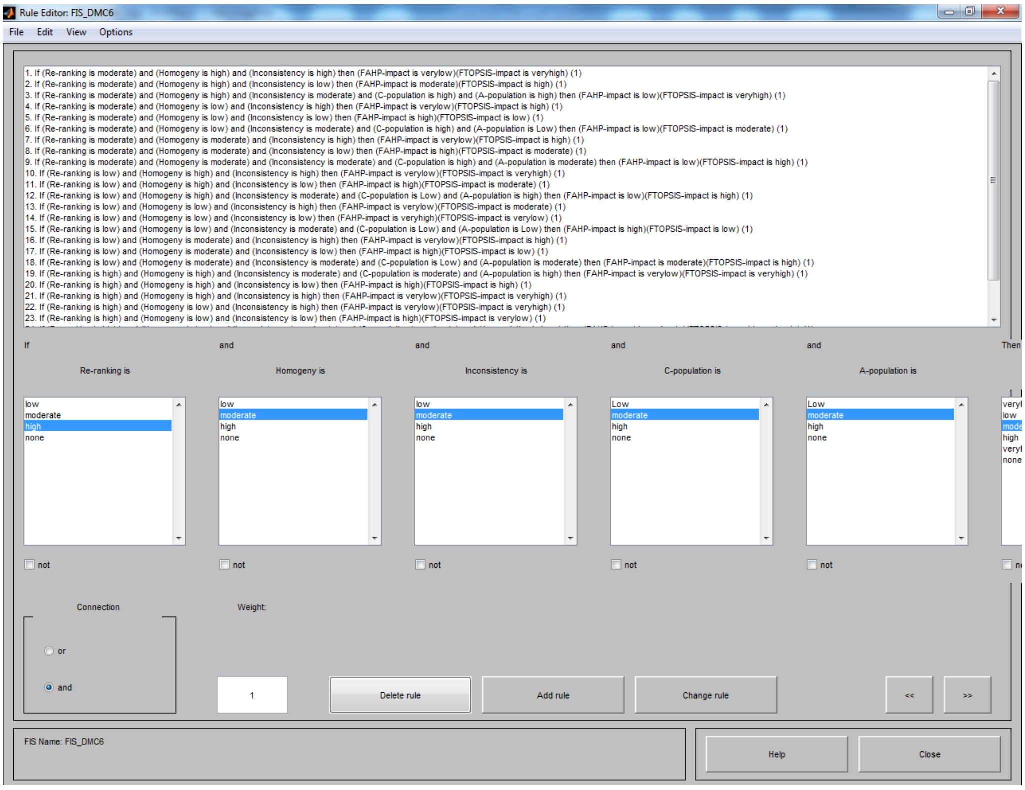


Figure 4.6: A part of designed rules

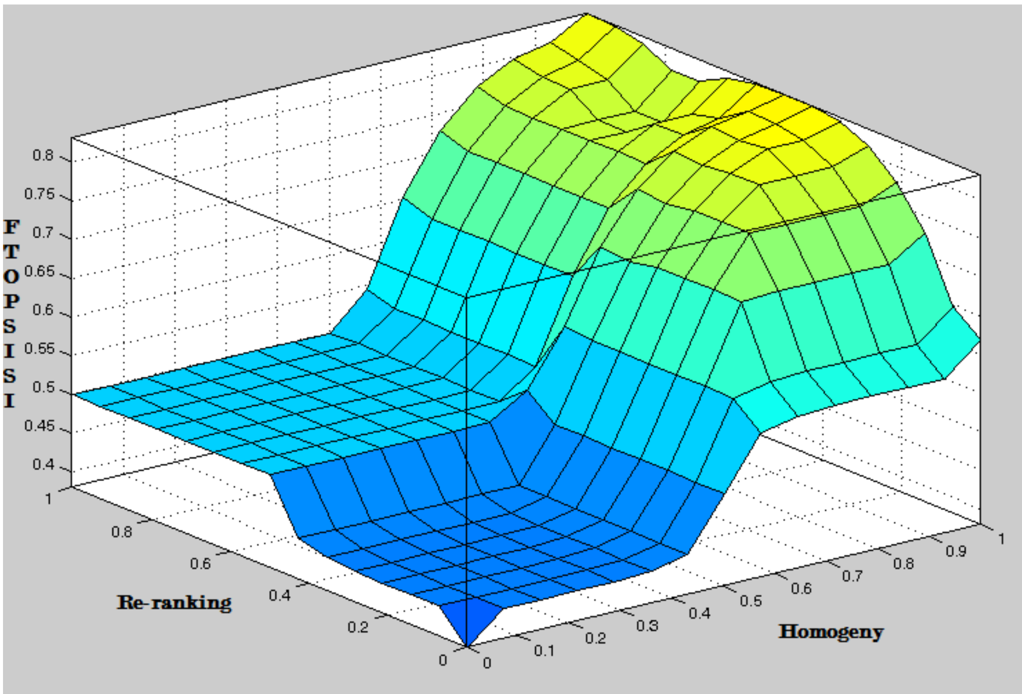


Figure 4.7: The surface view of rules for x inputs: Homogeny, y input: Reranking and Z output: FTOPSOSI

imapact. Increasing re-ranking and inconsistency in DM causes to increase the FTOPSIS impact. This plot shows that the implementation of rules in FIS is according to methods' attributes.

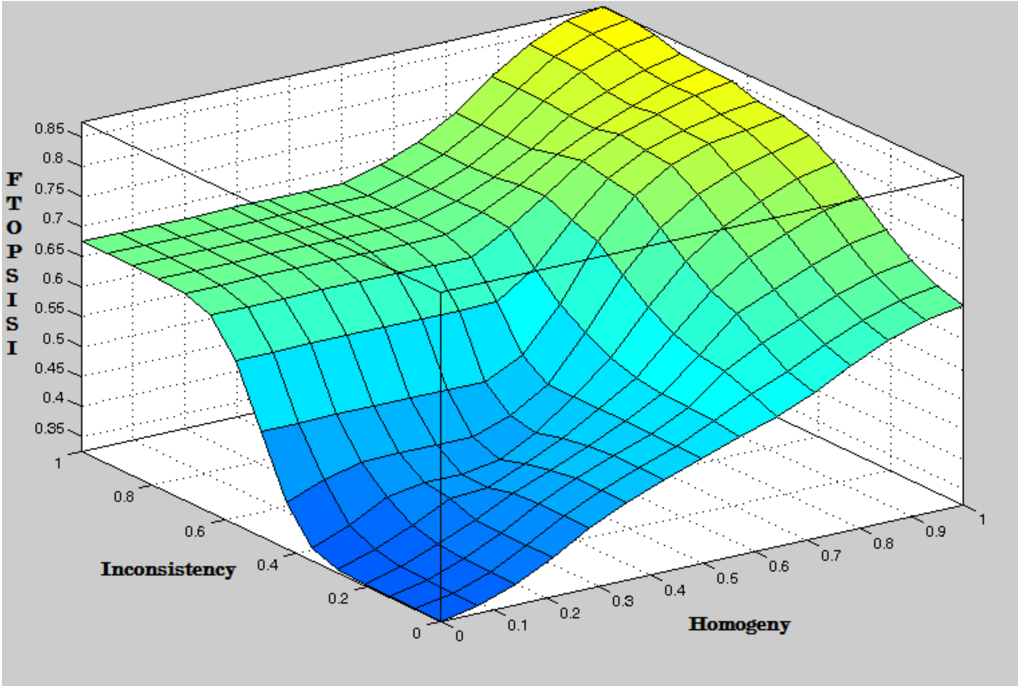


Figure 4.8: The surface view of rules for x inputs: Homogeny, y input: Inconsistency and Z output: FTOPSOSI

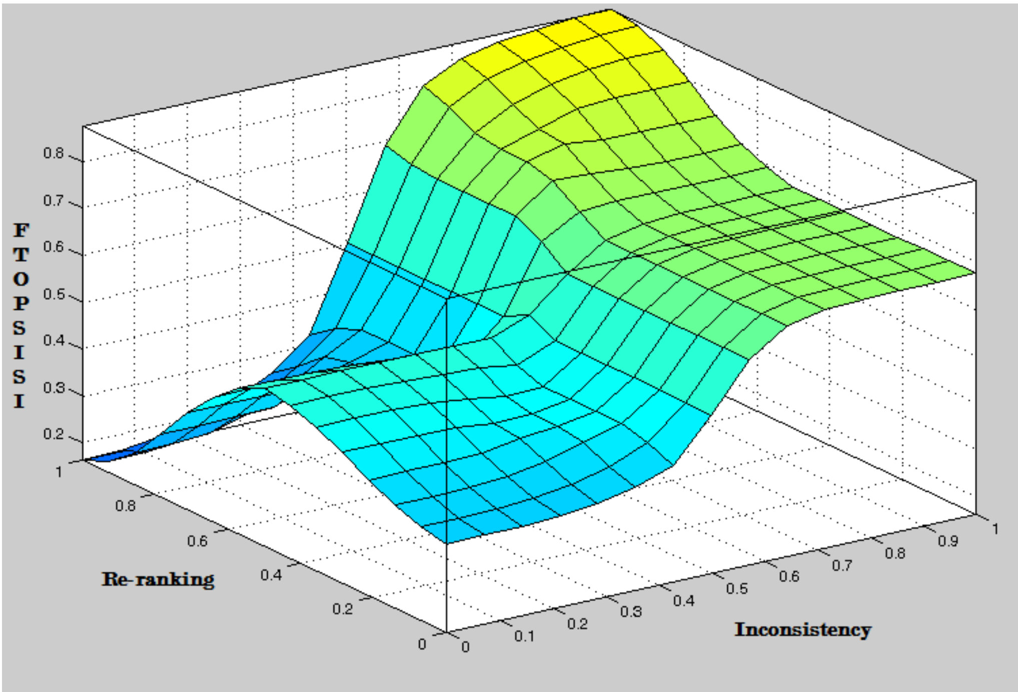


Figure 4.9: The surface view of rules for x inputs: Inconsistency, y input: Reranking and Z output: FTOPSOSI

Figure 4.10 shows the effectiveness of "Homogeny" and "Re-ranking" on FAHP imapact. Decreasing homogeny and re-ranking in DM causes to decrease the FAHP impact. This plot shows that the implementation of rules in FIS is according to methods' at-

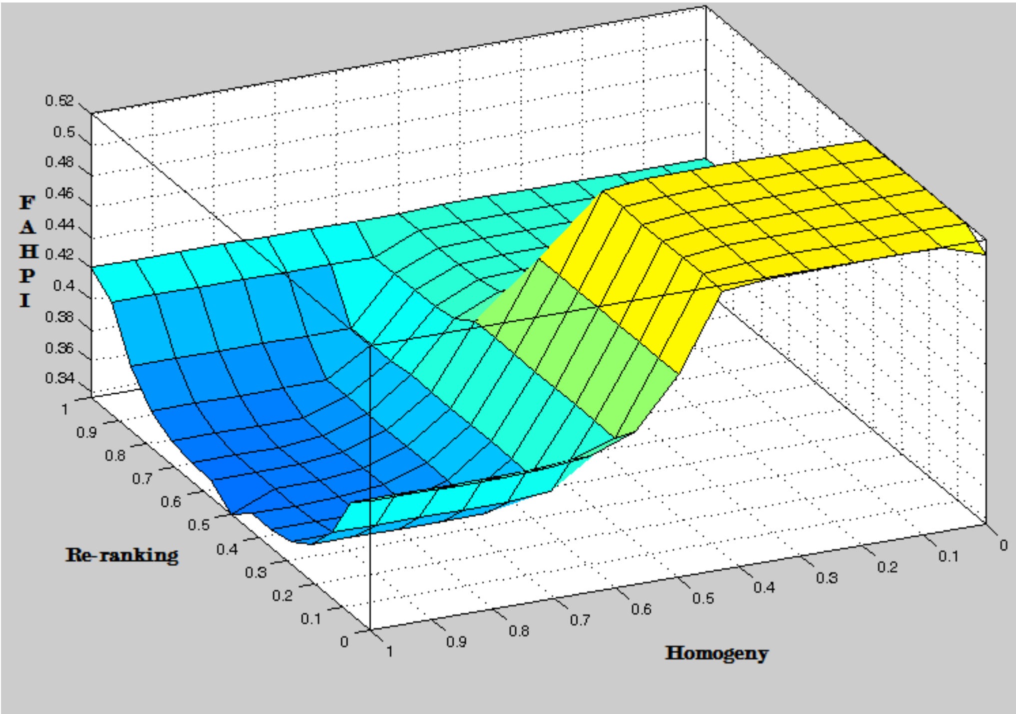


Figure 4.10: The surface view of rules for x inputs: Homogeny, y input: Reranking and Z output: FTOPSOSI

tributes.

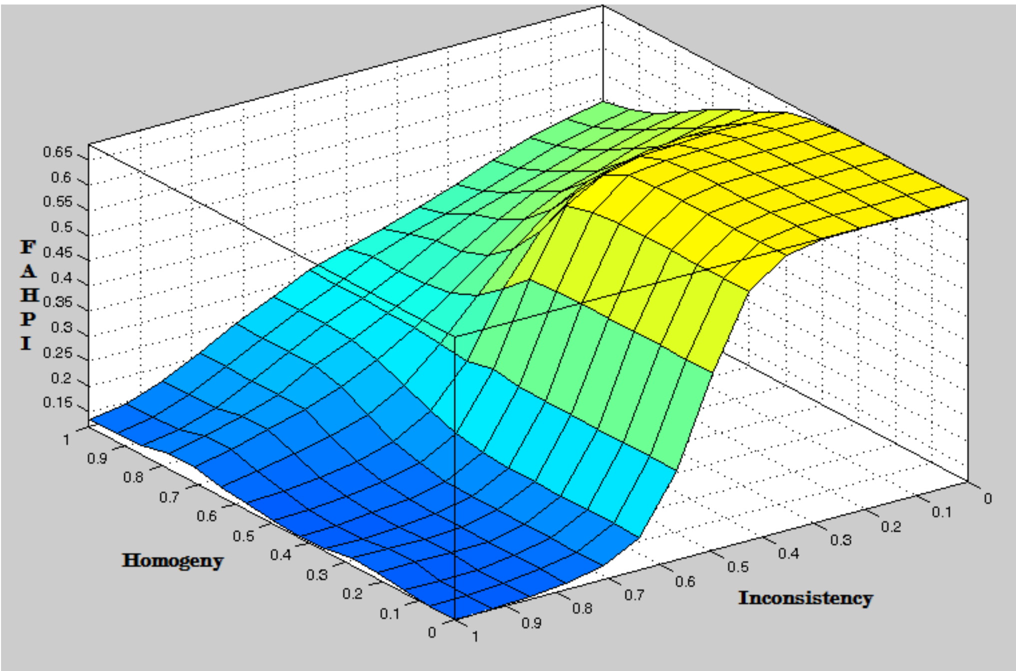


Figure 4.11: The surface view of rules for x inputs: Homogeny, y input: Inconsistency and Z output: FAHPI

Figure 4.11 shows the effectiveness of "Homogeny" and "Inconsistency" on FAHP imapact. Decreasing homogeny and inconsistency in DM causes to decrease the FAHP impact. This plot shows that the implementation of rules in FIS is according to methods' attributes.

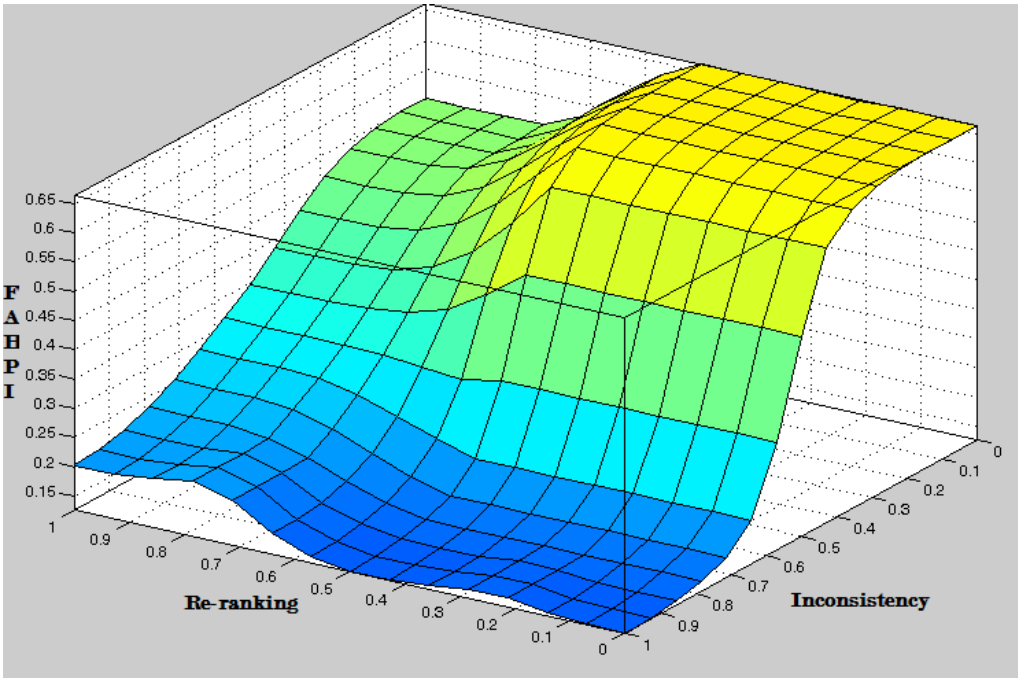


Figure 4.12: The surface view of rules for x inputs: Inconsistency, y input: Reranking and Z output: FAHP

Figure 4.12 shows the effectiveness of "Inconsistency" and "Re-ranking" on FAHP imapact. Decreasing re-ranking and inconsistency in DM causes to decrease the FAHP impact. This plot shows that the implementation of rules in FIS is according to methods' attributes.

The FIS defuzzifies the FAHPI and FTOPSISI and generate their crisp numbers which is usable in calculations. The crisp values of FAHPI and FTOPSISI are employed for alternative evaluation and final ranking.

4.6 Alternative Ranking Method

The suitable method for alternative evaluating is determined based on FIS' results. After determination of FAHPI and TOPSISI, the proper evaluation method is determined based on the following conditions:

- *If* FAHP impact is very low or FTOPSIS impact is very high, *then* FTOPSIS method should be selected for evaluation of alternative.

- *If* FAHP impact is very high and FTOPSIS is very low,*then* FAHP method should be selected for evaluation of alternative.

- The remainder conditions are combination conditions.

According the designed fuzzy MFs, when the impact is less than 0.32, it belongs to "very low" membership function and when the impact is greater than 0.68, it belongs to "very high" membership function (Fig.4.4 a, b).

Under combination condition, the evaluation of alternatives is doing by both AHP and TOPSIS methods. Accordingly, we get two separate set of alternatives' weights. Then we combine the obtained weights based on methods' impacts. Therefore, the set of final weights is built as:

$$F = [f_j]_J \; j = 1, 2, ..., J \tag{4.3}$$

Where

- J is number of alternatives.

- $F = \sqrt{HI \star TI}$. The multiplication operator is a kind of "element-wise" operations which multiply each entry in set HI with its corresponding entry in set TI.

- $TI = TOPSISI \star T$. Where $TOPSISI$ is variable with respect to FTOPSIS impact and T is set of alternative weighting obtained from FTOPSIS method as: $T = \left[t_j\right]_J$.

- $HI = AHPI \star H$. Where $AHPI$ is variable with respect to FAHP impact and H is set of alternative weighting obtained from FAHP method as: $H = [h_j]_J$.

The last stage of DFHM method is the final ranking of alternatives which is based on condition provided and correspond alternative weighting set (T, A or$F$).

The Median defuzzification method is employed to represent TFN with respect to decision makers' opinions as crisp values.

In FAHP method, the elements of pairwise comparison matrices assigne by TFN instead of crisp value and the addition operation on TFN uses for weighting of criteria.

In FTOPSIS, the addition and multiplication operators on TFN use to calculate PIS and NIS for ranking of suppliers. Vertex method employes to measure distance of each alternative from the PIS and the NIS, which cause to solve problem of doubling weightings on alternatives.

4.7 Summary

We proposed a Fuzzy dynamic Hybrid MCDM method (FDHM) for evaluation and ranking of alternatives in multi-attribute decision makings specially supplier management.

Three techniques are applied in this method to increase the efficiency of FDHM. The aim of this method is generating a ranking which is closer than current methods to experts' opinion.

FDHM receives the experts' ideas as input. The experts are effective decision makers in company and their opinion directly receive as fuzzy values to avoid the mistake in receiving their idea during data collection. The collected data includes ambiguous, non-available, incomplete, in part ignorance data. Therefore, we use fuzzy set theory to deal with them in decision analysis. The fuzzy set theory is employed in whole process of method not only data collection. We use fuzzy for following operations:

- Fuzzification of collecting data from decision makers,
- Weighting of criteria,

- Developing a Fuzzy Inference System (FIS),

- Evaluation and ranking of suppliers.

The determination and weighting of criteria is the first stage of method which carry out by FAHP method. The second stage of FDHM is evaluation and ranking of alternatives. The method for evaluation of alternatives is different in DMs. This is according to the environment of DM. FAHP, FTOPSIS or combination of them may applied in this stage.

FDHM is basically integration of FAHP and FTOPSIS. The integration of FAHP and FTOPSIS is controlled by a Fuzzy Inference System (FIS). The FIS receives the situation of DM and produce FAHP Impact (FAHPI) and FTOPSIS Impact(FTOPSISI). Then, the proper type of integration will be conducted based on methods'impact.

The procedure of FDHM performs in an efficient way, so it can increase the flexibility and accuracy of DM process. In next chapter we apply this method for Mobarakeh Steel Company (MSC) to show ability and precision of the proposed method in different DM situations.

CHAPTER 5

EVALUATION OF FDHM

5.1 Introduction

A best decision making method is the most close to experts' decision analysis (section 2.3). Therefore, the satisfaction of experts from a decision making method is a guaranty for that. We evaluate FDHM method through *satisfaction* and *efficiency* factors. For evaluation of "satisfaction" we test the method to investigate whether can fulfill the satisfaction of experts or not?

For evaluation of "efficiency" we compare the efficiency of FDHM with other methods in terms of accuracy and time complexity. Figure 5. 1 shows the process of evaluating FDHM method.

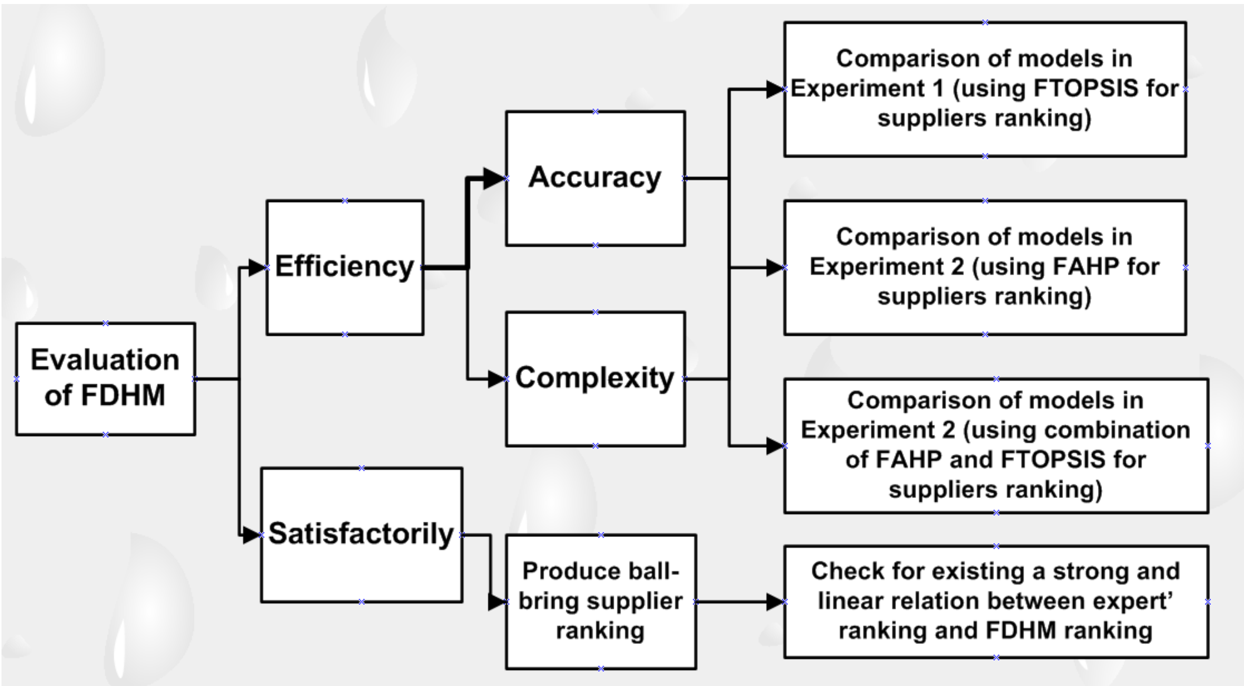


Figure 5.1: Evaluation process of FDHM

We apply the FDHM for supplier selection in Mobarakeh Steel Company (MSC) to evaluate the satisfaction factor of FDHM method. We compare the produced ranking by FDHM (FDHM' ranking) with the ranking resulted by experts' judgment (experts' ranking). The ability of method to handle the evaluation and to produce a ranking in high correlation coefficient with experts' ranking, imply the *satisfaction* of method to address supplier management.

We evaluate the efficiency of FDHM through the comparison of FDHM and the best static methods performance. The performance of each method is estimated in terms of accuracy and time complexity. The efficiency is evaluated in various experiments.

For evaluation of accuracy, we rank the suppliers using methods. Also we ask experts to rank the suppliers. Then we investigate that which method generate more near results to experts' judgment.

The Time Complexity (TC) of an DM method is expressed using big O notation, which excludes coefficients and lower order terms. Time complexity on DM methods is estimated by counting the number of comparison performed by the DM method. For example, if the time required by a method on n number of criteria and m number of alternatives is at most $5mn+n$, the asymptotic time complexity is $O(mn)$.

We start the evaluation of FDHM by ball-bring suppliers evaluation that is presented in next section.

5.2 Supplier selection using FDHM

Supplier selection is an MCDM problem, which should defined in the form of suppliers and criteria. For solving this problem, the set of suppliers be evaluated by related criteria then according evaluation results, the best supplier is selected.

In this section, we evaluate and rank suppliers to select the best supplier for supplement of ball-bearing in spare part supplement section of MSC using the proposed method. Through the announcement of the company, eight suppliers declared their willing to supply ball-bearing. The suppliers are Kahroba (S1), Barghara (S2), Rahbaran Foolad (S3), Alitajhiz (S4), Veghar Kavir (S5), Tadavom Sanaye (S6), Tara (S7), Mattex (S8).

For evaluation of mentioned suppliers, we determine a set of criteria based on data collection from the experts of Mobarake steel company (Appendix E). The criteria are determined as:

- Technical Abilities (TA),
- Quality Assurance (QA),
- On time Delivery (OD),
- Financial Capacity (FC).

In following we decompose the problem into a hierarchy of criteria and suppliers (Fig. 5.2). We construct all comparison matrices and prepare related questioners based on this hierarchy tree (Appendix E).

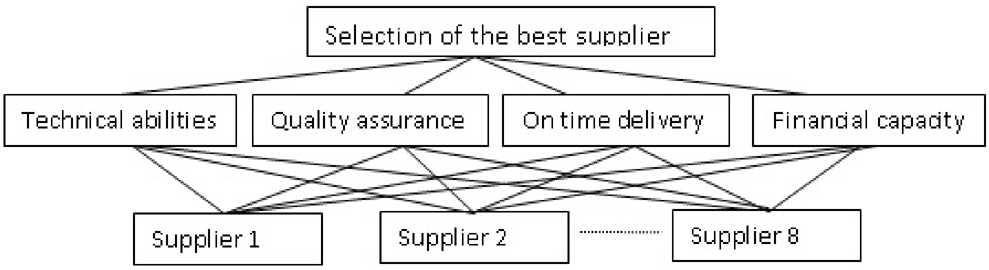


Figure 5.2: decision hierarchy for supplier selection

The method employs FAHP for weighting of criteria. The FIS determines the impact of FAHP method and FTOPSIS. The method for evaluation of suppliers is based on impact factors.

5.2.1 Criteria Weighting

After the establishment of decision hierarchy tree, FAHP method is applied for weighting of criteria. In this step, decision makers in MSC fill part C and D of questioners (Appendix E) by using the linguistic scale given in section 4.4. We aggregate and defuzzify the answers of questioners. Then, we placed in a pairwise comparison matrix which is presented in Table 5.1.

Table 5.1: Fuzzy comparison matrix of criteria

Criteria	TA	QA	OD	FC
TA	$(1,1,1)$	$(4,5,6)$	$(1,2,3)$	$(3,4,5)$
QA	$(1/6,1/5,1/4)$	$(1,1,1)$	$(1/5,1/4,1/3)$	$(1/3,1/2,1)$
OD	$(1/3,1/2,1)$	$(3,4,5)$	$(1,1,1)$	$(2,3,4)$
FC	$(1/5,1/4,1/3)$	$(1,2,3)$	$(1/4,1/3,1/2)$	$(1,1,1)$

After defuzzification of pairwise comparison matrix elements, the equations (2.11), (2.12) and (2.13) have been applied to obtain the results presented in Table 5.2.

Table 5.2: Ranking criteria resulting FAHP

Criteria	Weight	Rank
TA	0.493832	1
OD	0.304031	2
FC	0.120493	3
QA	0.0816435	4

The results shows that, respectively technical abilities, on time delivery, financial capacity and quality assurance are important criteria for supplier selection.

The inconsistency ratio of the pairwise comparison matrix calculated using equations (2.14) and (2.15) as $IR = 0.0113089$.

Therefore, the obtained weights are properly consistent and usable in the process of selection.

5.2.2 Supplier evaluation method

The proper method for evaluation of suppliers is based on environment of DM. The situation of environment' element is reported by experts. We requested the experts' team to fill questioners regarding evaluation of pure fuzzy inputs as probability of inconsistency, Re-ranking and rate of alternatives homogeneous. Also we asked them to report the list of suppliers for A-population element.

The rate of environment' elements resulted by aggregation of experts' answers are:

- Re-ranking: 0.213
- Homogeny: 0.865
- Inconsistency: 0.752
- C-population: 4
- A-population: 8

In this stage, FIS *(i)* fuzzifies crisp values according defined MFs, *(ii)* executes all the rules with the determined input [0.213 0.865 0.752 4 8] and *(iii)* aggregates “then” section of rules using the COA method (section 4.5) to achieve related output as:

- FAHPI: 0.244
- FTOPSISI: 0.814

Figure 5.3 shows the rules which get involved in calculation of impacts through the considered input.

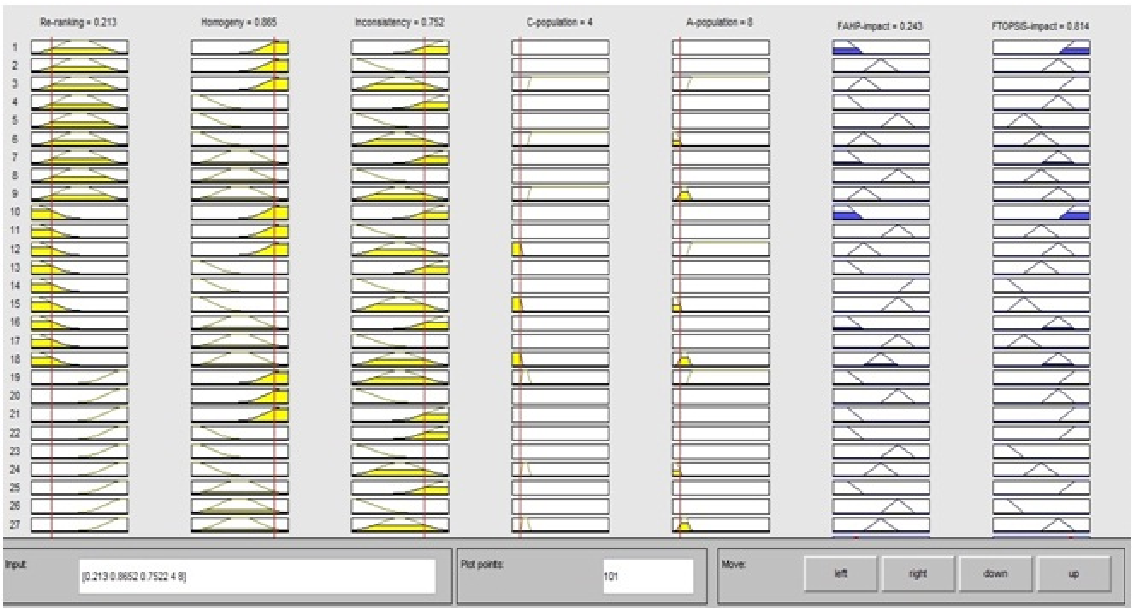


Figure 5.3: View of rules with related inputs

The FAHPI is 0.244 that is considered as “very low” and FTOPSISI is 0.814 that is considered as “very high” (refer section 4.5). The obtained conditions of FAHPI and FTOPSISI is used for determination of proper method for supplier evaluation.

According FDHM when the FAHPI is very low and FTOPSISI is very high then FTOPSIS is the best method for evaluation and ranking of suppliers.

5.2.3 Supplier Ranking and selection

According FIS’ output FAHP impact is very low and FTOPSIS impact is very high. In this condition FTOPSIS is selected for evaluation and ranking of suppliers. Hence through following steps we achieve rank of suppliers:

Step1: Fuzzy performance rating matrix is constructed and the aggregated experts’ judgments is inserted to this matrix. Table 5.3 shows the elements of this matrix in terms of linguistic variables.

Table 5.3: Linguistic performance rating matrix

	TA	OD	FC	QA
S1	good	fairly good	preferable	absolute
S2	preferable	good	very good	fairly good
S3	perfect	week average	fairly good	equal
S4	equal	very good	good	very good
S5	week average	preferable	week average	good
S6	very good	absolute	preferable	perfect
S7	preferable	perfect	absolute	not bad
S8	not bad	not bad	perfect	week average

Then the corresponding TFN which is obtained from Table 4.1, is used to convert the experts’ opinion to fuzzy values(Table 5.4).

Step2: Weighted normalized fuzzy decision matrix is constructed using equation (2.8). The elements of this matrix is presented in Table 5.5.

Step3: Positive-ideal A^* and negative ideal A^- solutions is determined using equation (2.16, 2.17). In this case all the criteria are benefit criteria therefore from equa-

Table 5.4: Fuzzy performance rating matrix

	TA	OD	FC	QA
S1	$(4,5,6)$	$(5,6,7)$	$(3,4,5)$	$(7,8,9)$
S2	$(3,4,5)$	$(4,5,6)$	$(6,7,8)$	$(5,6,7)$
S3	$(8,9,10)$	$(1,2,3)$	$(5,6,7)$	$(1,1,1)$
S4	$(1,1,1)$	$(6,7,8)$	$(4,5,6)$	$(6,7,8)$
S5	$(1,2,3)$	$(3,4,5)$	$(1,2,3)$	$(4,5,6)$
S6	$(6,7,8)$	$(7,8,9)$	$(3,4,5)$	$(8,9,10)$
S7	$(3,4,5)$	$(8,9,10)$	$(7,8,9)$	$(2,3,4)$
S8	$(2,3,4)$	$(2,3,4)$	$(8,9,10)$	$(1,2,3)$

Table 5.5: Weighted Fuzzy performance rating matrix

	TA	OD	FC	QA
S1	$(2.00,2.50,3.00)$	$(1.50,1.80,2.10)$	$(0.36,0.48,0.60)$	$(0.56,0.64,0.72)$
S2	$(1.50,2.00,2.50)$	$(1.20,1.50,1.80)$	$(0.72,0.84,0.96)$	$(0.40,0.48,0.56)$
S3	$(4.00,4.50,5.00)$	$(0.30,0.60,0.90)$	$(0.60,0.72,0.84)$	$(0.08,0.08,0.08)$
S4	$(0.50,0.50,0.50)$	$(1.80,2.10,2.40)$	$(0.48,0.60,0.72)$	$(0.48,0.56,0.64)$
S5	$(0.50,1.00,1.50)$	$(0.90,1.20,1.50)$	$(0.12,0.24,0.36)$	$(0.32,0.40,0.48)$
S6	$(3.00,3.50,4.00)$	$(2.10,2.40,2.70)$	$(0.36,0.48,0.60)$	$(0.64,0.72,0.80)$
S7	$(1.50,2.00,2.50)$	$(2.40,2.70,3.00)$	$(0.84,0.96,1.08)$	$(0.16,0.24,0.32)$
S8	$(1.00,1.50,2.00)$	$(0.60,0.90,1.20)$	$(0.96,1.08,1.20)$	$(0.08,0.16,0.24)$

tion (2.16), $\left(max\, v_i \mid i \in I^{'}\right)$ is applied to determine A^*, and from equation (2.17), $\left(min\, v_i \mid i \in I^{'}\right)$ is employed to reach A^-. Table 5.6 shows the considered positive and negative ideal solutions.

Table 5.6: PIS and NIS for evaluation of suppliers

	TA	OD	FC	QA
A^*	(4.00, 4.50, 5.00)	(2.40, 2.70, 3.00)	(0.96, 1.08, 1.20)	(0.64, 0.72, 0.80)
A^-	(0.50, 0.50, 0.50)	(0.30, 0.60, 0.90)	(0.12, 0.24, 0.36)	(0.08, 0.08, 0.08)

Step4: The distance of suppliers from the positive and negative ideal solutions is calculated. The distance of each supplier from A^* and A^- are calculated using equations (2.18) and (2.19) respectively.

Calculation of the distance between A^* and $S1$:

$$D_1^* = \sqrt{\frac{1}{3}\left[(4.00-2.00)^2+(4.50-2.50)^2+(5.00-3.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(2.40-1.50)^2+(2.70-1.80)^2+(3.00-2.10)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.96-0.36)^2+(1.08-0.48)^2+(1.20-0.60)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.64-0.56)^2+(0.72-0.64)^2+(0.80-0.72)^2\right]}$$

$$=3.58$$

Calculation of the distance between A^- and $S1$:

$$D_1^- = \sqrt{\frac{1}{3}\left[(0.50-2.00)^2+(0.50-2.50)^2+(0.50-3.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.30-1.50)^2+(0.60-1.80)^2+(0.90-2.10)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.12-0.36)^2+(0.24-0.48)^2+(0.36-0.60)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.08-0.56)^2+(0.08-0.64)^2+(0.08-0.72)^2\right]}$$

$$=4.33$$

Calculation of the distance between A^* and $S2$:

$$D_2^* = \sqrt{\frac{1}{3}\left[(4.00-1.50)^2+(4.50-2.00)^2+(5.00-2.50)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(2.40-1.20)^2+(2.70-1.50)^2+(3.00-1.80)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.96-0.72)^2+(1.08-0.84)^2+(1.20-0.96)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.64-0.40)^2+(0.72-0.48)^2+(0.80-0.56)^2\right]}$$

$$=4.40$$

Calculation of the distance between A^- and $S2$:

$$D_2^- = \sqrt{\frac{1}{3}\left[(0.50-1.50)^2+(0.50-2.00)^2+(0.50-2.50)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.30-1.20)^2+(0.60-1.50)^2+(0.90-1.80)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.12-0.72)^2+(0.24-0.84)^2+(0.36-0.96)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.08-0.40)^2+(0.08-0.48)^2+(0.08-0.56)^2\right]}$$

$$= 3.455$$

Calculation of the distance between A^* and $S3$:

$$D_3^* = \sqrt{\frac{1}{3}\left[(4.00-4.00)^2+(4.50-4.50)^2+(5.00-5.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(2.40-0.03)^2+(2.70-0.60)^2+(3.00-0.9)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.96-0.60)^2+(1.08-0.72)^2+(1.20-0.84)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.64-0.08)^2+(0.72-0.08)^2+(0.80-0.08)^2\right]}$$

$$= 2.9403$$

Calculation of the distance between A^- and $S3$:

$$D_3^- = \sqrt{\frac{1}{3}\left[(0.50-4.00)^2+(0.50-4.50)^2+(0.50-5.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.30-0.30)^2+(0.60-0.60)^2+(0.90-0.90)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.12-0.60)^2+(0.24-0.72)^2+(0.36-0.84)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.08-0.08)^2+(0.08-0.08)^2+(0.08-0.08)^2\right]}$$

$$= 4.50$$

Calculation of the distance between A^* and $S4$:

$$D_4^* = \sqrt{\frac{1}{3}\left[(4.00-0.50)^2+(4.50-0.50)^2+(5.00-0.50)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(2.40-1.80)^2+(2.70-2.10)^2+(3.00-2.40)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.96-0.48)^2+(1.08-0.60)^2+(1.20-0.72)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.64-0.48)^2+(0.72-0.56)^2+(0.80-0.64)^2\right]}$$

$$= 5.26$$

Calculation of the distance between A^- and $S4$:

$$D_4^- = \sqrt{\frac{1}{3}\left[(0.50-0.50)^2+(0.50-0.50)^2+(0.50-0.50)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.30-1.80)^2+(0.60-2.10)^2+(0.90-2.40)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.12-0.48)^2+(0.24-0.60)^2+(0.36-0.72)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.08-0.48)^2+(0.08-0.56)^2+(0.08-0.64)^2\right]}$$

$$= 2.344$$

Calculation of the distance between A^* and $S5$:

$$D_5^* = \sqrt{\frac{1}{3}\left[(4.00-0.50)^2+(1.00-4.50)^2+(1.50-5.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.90-2.40)^2+(1.20-2.70)^2+(1.50-3.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.96-0.12)^2+(1.08-0.24)^2+(1.20-0.36)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.64-0.32)^2+(0.72-0.48)^2+(0.80-0.48)^2\right]}$$

$$=6.13563$$

Calculation of the distance between A^- and $S5$:

$$D_5^- = \sqrt{\frac{1}{3}\left[(0.50-0.50)^2+(0.50-1.00)^2+(0.50-1.50)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.30-0.90)^2+(0.60-1.20)^2+(0.90-1.50)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.12-0.12)^2+(0.24-0.24)^2+(0.36-0.36)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.08-0.32)^2+(0.08-0.40)^2+(0.08-0.48)^2\right]}$$

$$=1.57158$$

Calculation of the distance between A^* and $S6$:

$$D_6^* = \sqrt{\frac{1}{3}\left[(4.00-3.00)^2+(4.50-3.50)^2+(5.00-4.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(2.40-2.10)^2+(2.70-2.40)^2+(3.00-2.70)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.96-0.36)^2+(1.08-0.48)^2+(1.20-0.60)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.64-0.64)^2+(0.72-0.72)^2+(0.80-0.80)^2\right]}$$

$$=1.90$$

Calculation of the distance between A^- and $S6$:

$$D_6^- = \sqrt{\frac{1}{3}\left[(0.50-3.00)^2+(0.50-3.50)^2+(0.50-4.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.30-2.10)^2+(0.60-2.40)^2+(0.90-2.70)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.12-0.36)^2+(0.24-0.48)^2+(0.36-0.60)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.08-0.64)^2+(0.08-0.72)^2+(0.08-0.80)^2\right]}$$

$$=5.71$$

Calculation of the distance between A^* and $S7$:

$$D_7^* = \sqrt{\frac{1}{3}\left[(4.00-1.50)^2+(4.50-2.00)^2+(5.00-2.50)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(2.40-2.40)^2+(2.70-2.70)^2+(3.00-3.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.96-0.84)^2+(1.08-0.96)^2+(1.20-1.08)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.64-0.16)^2+(0.72-0.24)^2+(0.80-0.32)^2\right]}$$

$$=3.10$$

Calculation of the distance between A^- and $S7$:

$$D_7^- = \sqrt{\frac{1}{3}\left[(0.50-1.50)^2+(0.50-2.00)^2+(0.50-2.50)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.30-2.40)^2+(0.60-2.70)^2+(0.90-3.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.12-0.84)^2+(0.24-0.96)^2+(0.36-1.08)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.08-0.16)^2+(0.08-0.24)^2+(0.08-0.32)^2\right]}$$

$$=4.54$$

Calculation of the distance between A^* and $S8$:

$$D_8^* = \sqrt{\frac{1}{3}\left[(4.00-1.00)^2+(4.50-1.50)^2+(5.00-2.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(2.40-0.60)^2+(2.70-0.90)^2+(3.00-1.20)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.96-0.96)^2+(1.08-1.08)^2+(1.20-1.20)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.64-0.08)^2+(0.72-0.16)^2+(0.80-0.24)^2\right]}$$

$$= 5.36$$

Calculation of the distance between A^- and $S8$:

$$D_8^- = \sqrt{\frac{1}{3}\left[(0.50-1.00)^2+(0.50-1.50)^2+(0.50-2.00)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.30-0.60)^2+(0.60-0.90)^2+(0.90-1.20)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.12-0.96)^2+(0.24-1.08)^2+(0.36-1.20)^2\right]}$$

$$+\sqrt{\frac{1}{3}\left[(0.08-0.08)^2+(0.08-0.16)^2+(0.08-0.24)^2\right]}$$

$$= 2.32$$

Step5: The similarities to ideal solution or satisfaction degree using equation (2.20) is calculated.

Calculation of CC_1^- for S1:

$$CC_1^- = \frac{D_1^-}{D_1^* + D_1^-} = 0.54740$$

Calculation of CC_2^- for S2:

$$CC_2^- = \frac{D_2^-}{D_2^* + D_2^-} = 0.43984$$

Calculation of CC_3^- for S3:

$$CC_3^- = \frac{D_3^-}{D_3^* + D_3^-} = 0.60483$$

Calculation of CC_4^- for S4:

$$CC_4^- = \frac{D_4^-}{D_4^* + D_4^-} = 0.30789$$

Calculation of CC_5^- for S5:

$$CC_5^- = \frac{D_5^-}{D_5^* + D_5^-} = 0.20389$$

Calculation of CC_6^- for S6:

$$CC_6^- = \frac{D_6^-}{D_6^* + D_6^-} = 0.75032$$

Calculation of CC_7^- for S7:

$$CC_7^- = \frac{D_7^-}{D_7^* + D_7^-} = 0.5942$$

Calculation of CC_8^- for S8:

$$CC_8^- = \frac{D_8^-}{D_8^* + D_8^-} = 0.3024$$

Step6: Finally, Ranking suppliers according to their CC_j^-, in descending order (Table 5.7).

Table 5.7: supplier ranking

Suppliers	Satisfaction degree CC_j^-	Ranking
Tadavom Sanaye (S6)	0.75032	1
Rahbaran Foolad (S3)	0.60483	2
Tara (S7)	0.59420	3
Kahroba (S1)	0.54740	4
Barghara (S2)	0.43984	5
Alitajhiz (S4)	0.30789	6
Mattex (S8)	0.30240	7
Veghar Kavir (S5)	0.20389	8

5.2.4 Satisfaction rate

The FDHM is applied in Mobarakeh Steel Company (MSC) for evaluation of ball-bring suppliers with a specific environment. Also experts have been asked to evaluate the same suppliers in the same DM environment. The rankings produced by FDHM and experts is presented in table(5.8). The experts rank the suppliers through a group decision making. Therefore, the produced ranking is aggregated of all experts' judgments.

Table 5.8: Rank of suppliers by experts team and supplier evaluation methods

Rank	Experts' ranking	FDHM' ranking
1	Tadavom Sanaye (S6)	Tadavom Sanaye (S6)
2	Rahbaran Foolad (S3)	Rahbaran Foolad (S3)
3	Tara (S7)	Tara (S7)
4	Kahroba (S1)	Kahroba (S1)
5	Barghara (S2)	Barghara (S2)
6	Alitajhiz (S4)	Alitajhiz (S4)
7	Mattex (S8)	Veghar Kavir (S5)
8	Veghar Kavir (S5)	Mattex (S8)

The FDHM' ranking and experts' ranking are presented as a data set in table 5.9, to analysis their Pearson Correlation Coefficient (CC) using SPSS.

Table 5.9: Rankings' data set

Rank	Experts' ranking	FDHM' ranking
1	6	6
2	3	3
3	7	7
4	1	1
5	2	2
6	4	4
7	8	5
8	5	8

We investigate the relation between FDHM' ranking and experts' ranking through their correlation coefficient. The FDHM method' ranking with $r - value = 1.000$ has very strong linear relation with experts' ranking. The p-value for FHM is less than 0.01, so the correlation is significant at the 0.01 level (Table 5.10).

Table 5.10: CC of FDHM' ranking with experts' ranking

Pearson CC (r-value)	p-value	Number of suppliers
1.000	0.0E0	8

The results shows that the produced ranking resulted by FDHM is equal to expert's ranking. Figure (5.4) illustrates the high CC between FDHM' rankings and experts' ranking. The X axis is the experts' ranking and the Y axis is the FDHM' ranking.

Also the satisfaction rate is calculated in experiment 1, 2 and 3. The results shows that the produced ranking resulted by FDHM is closed to expert's ranking (Fig. 5.5).

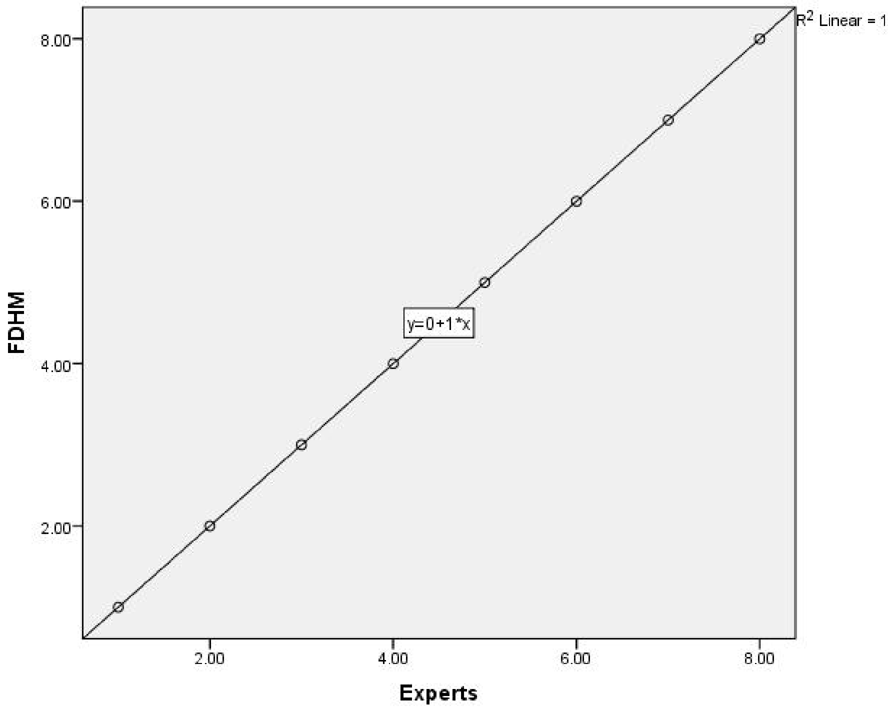


Figure 5.4: Correlation of FDHM' ranking and experts' ranking

experiment	Number of supplier	Satisfaction rate
Ball-breang suppliers	8	100%
Fasteners' suppliers	20	89.2%
WWD suppliers	20	99.8%
Chain' suppliers	10	89.1%

Figure 5.5: Correlation of FDHM' ranking and experts' ranking

The ability of method to handle the evaluation and to produce a ranking in high correlation coefficient with experts' ranking, imply the *satisfaction* of method to address supplier management. In this case, FDHM has achieved complete satisfaction of experts.

5.3 Efficiency of FDHM

The efficiency of FDHM is evaluated by comparing its performance with the best static methods in different experiments.

FDHM has three strategies for evaluation of suppliers. According FAHPI and FTOPSISI, one of these strategies is selected for supplier evaluation(figure 4.1). The various decision makings in MSC are surveyed based on their environment. We select three of them as the experiments. The environments of selected DMs can provide the three considered strategies. The experiments are as follow:

- **Experiment 1**, is the evaluation of fasteners' suppliers. The environment of this DM caused to choose FTOPSIS method as supplier evaluation method.
- **Experiment 2**, is the evaluation of Welding Wire-Electrodes (WWE)' suppliers. The environment of this DM caused to choose FAHP method as supplier evaluation method.
- **Experiment 3**, is the evaluation of chains' suppliers. The environment of this DM caused to combine FTOPSIS nad FAHP methods for supplier evaluation.

We carry out these experiments corresponding to these strategies. We evaluate the *efficiency* of FDHM through these experiments.

In each experiment we compare FDHM with two other SES decision making methods in the same environment and conditions. These methods are the only possible methods composing from candidate methods.(Refer section 3.2). The methods are:

i) Fuzzy Hybrid Method (FHM): This method is the static hybridization of FAHP and FTOPSIS. The FAHP is used for weighting of criteria. The FTOPSIS is applied to evaluate the suppliers.

ii) Fully FAHP Method(FFAHP): FAHP methods is applied for weighting of criteria as well as evaluation of alternatives. This method frequently is employed for supplier managements.(Refer section 2.3.4)

We compare the performance of FDHM with FHM and FFAHP to evaluate the efficiency of FDHM. The comparison is from the aspects of accuracy and time complexity.

The accuracy is the first priority to determine the efficiency of FDHM in supplier management as the managers insist on accuracy more than time complexity.

For evaluation of accuracy, the comparisons of rankings are based on expert' ranking. In each experiment we rank the suppliers using FDHM, FFAHP and FHM methods. Also we ask 20 experts to evaluate and rank the suppliers in a group decision making. Then we investigate the relation between the produced rankings thorough Pearson' Correlation Coefficient(CC). The method which generate a rank with higher CC to experts' ranking is more accurate than other methods.(Appendix F involves the complete CC results)

Time complexity is achieved by counting the number of comparisons. We calculate the time complexity of methods in supplier evaluation part of methods.

In each experiment we calculate the time complexity of methods in same conditions. In first stage of methods (weighting criteria), they have same number of comparison due to they used the same method for weighting criteria (FAHP). Therefore, we calculate the number of comparisons for the second stage (alternative evaluation).

5.3.1 Expriment1: using FTOPSIS for suppliers ranking

In this experiment we choose fasteners' suppliers evaluation. The environment of this DM is presented as:

- Re-ranking: 0.800
- Homogeny: 0.700
- Inconsistency: 0.700
- C-population: 18
- A-population: 20

The suitable method for alternative evaluating is determined based on FIS' results. The experiment 1 provides a set of input as [0.8 0.7 0.7 18 20] to prepare the conditions to select FTOPSIS for supplier evaluation. According the considered input, the FIS generate the output as:

- FAHPI: 0.255
- FTOPSISI: 0.766

Figure 5.6 shows the rules which get involved in calculation of impacts through enter the considered input.

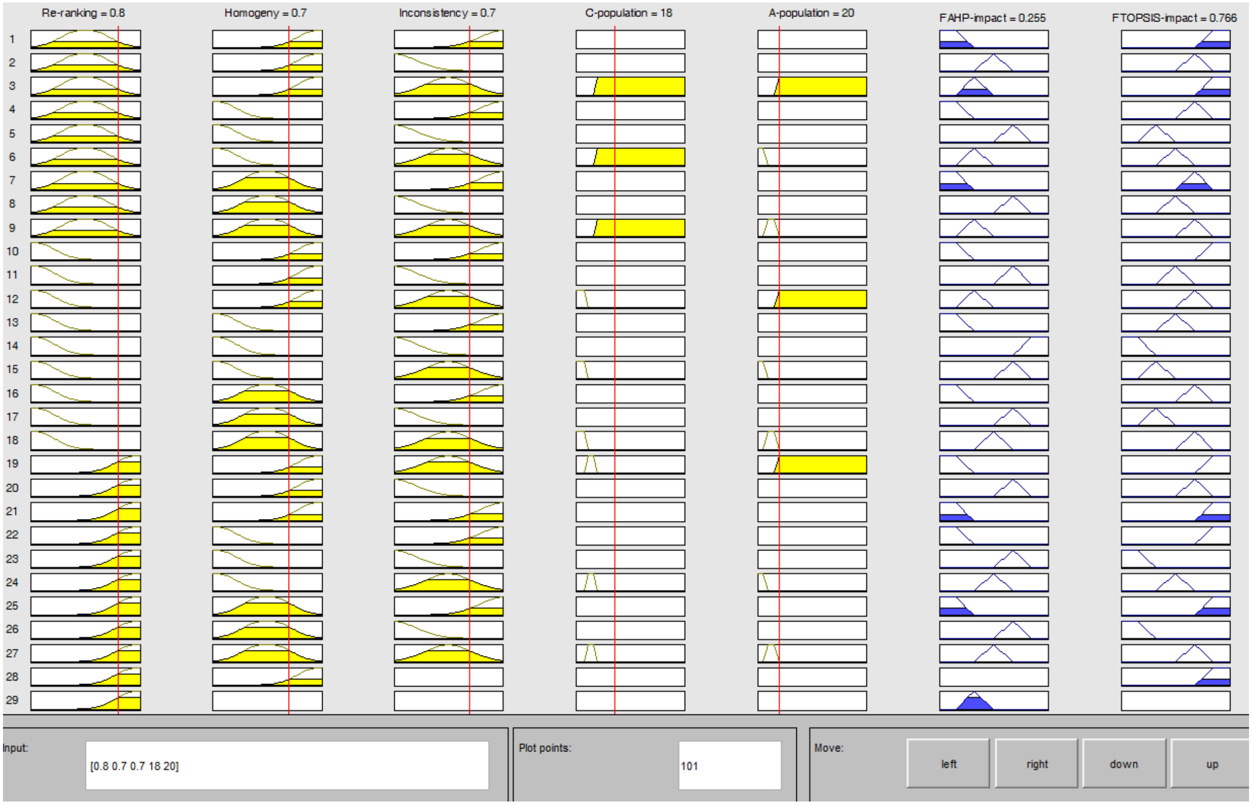


Figure 5.6: The rules' view of FIS with input[0.8 0.7 0.7 18 20]

According the designed fuzzy MFs, when the impact is less than 0.32, it belongs to "very low" membership function and when the impact is greater than 0.68, it belongs to "very high" membership function (Refer section 4.5).

Therefore, the FTOPSIS as proper evaluation method is determined based on the following condition:

If FAHP impact is very low or FTOPSIS impact is very high, *then* FTOPSIS method should be selected for evaluation of alternative.

The FDHM employs FTOPSIS in stage of suppliers evaluation and ranking. Also the rankings are produced by FHM and FFAHP as well as experts' team. The results of ranking is presented in table 5.11.

Table 5.11: Experiment 1, suppliers' ranking

Rank	Experts' ranking	FHM' ranking	FFAHP' ranking	FDHM' ranking
1	S1	S1	S7	S1
2	S20	S20	S5	S20
3	S7	S7	S1	S7
4	S5	S5	S20	S5
5	S18	S15	S6	S15
6	S15	S18	S18	S18
7	S6	S6	S15	S6
8	S16	S16	S16	S16
9	S59	S9	S11	S9
10	S10	S4	S10	S4
11	S11	S11	S9	S11
12	S13	S10	S13	S10
13	S4	S13	S4	S13
14	S14	S14	S12	S14
15	S3	S3	S3	S3
16	S2	S2	S2	S2
17	S12	S12	S14	S12
18	S17	S17	S19	S17
19	S19	S19	S8	S19
20	S8	S8	S17	S8

The Pearson correlation coefficients (r-value), significance values (p-value), and the number of cases with non-missing values (N) of the method' rankings and experts' ranking is calculated and presented in table 5.12. The data is collected for 20 suppliers, so the value of N is 20.

The result of correlation analysis in table 5.13 shows that the ranking produced by FDHM method with $r-value = .892$ has very strong and linear relation with experts' ranking. The $p-value$ for FDHM is less than 0.01, so the correlation is significant at the 0.01 level.

The ranking produced by FHM method with $r - value = .892$ has very strong and linear relation with experts' ranking. The $p - value$ for FHM is less than 0.01, so the correlation is significant at the 0.01 level.

The p-value for FHM is greater than 0.05, so we are not confident about the relation between FHM' ranking and expert' ranking.

Table 5.12: Experiment 1, CC of methods' rankings with experts' ranking

method	Pearson CC (r-value)	p-value	Number of suppliers
FDHM	0.892	0.000	20
FHM	0.892	0.000	20
FFAHP	0.265	0.259	20

Figure (5.7) illustrates the difference in correlation between various methods' rankings and experts' ranking. The X axis is the experts' ranking and the Y axis is the methods' ranking. The FDHM and FHM have the same fit line.

The CC imply the accuracy of methods. So, FDHM and FHM have the same accuracy as well as the highest accuracy which caused by using same method for evaluation of suppliers.

The Time Complexity (TC) of methods is calculated based on the number of comparisons. In this experiment, the FHM and FDHM have the same process as FTOPSIS is selected by FIS for evaluation of suppliers. Therefor, FHM and FDHM have the same TC. They have one comparison matrix with m rows and n columns as n is the number of criteria and m is the number of suppliers. So, when the TC_x is the TC of x method then:

$$TC_{FDHM} = TC_{FHM} = TC_{FTOPSIS} = O(m \cdot n)$$

FFAHP has n comparison matrices corresponding to the number of criteria. In each matrix, the number of comparisons is $m \cdot m$, therefore:

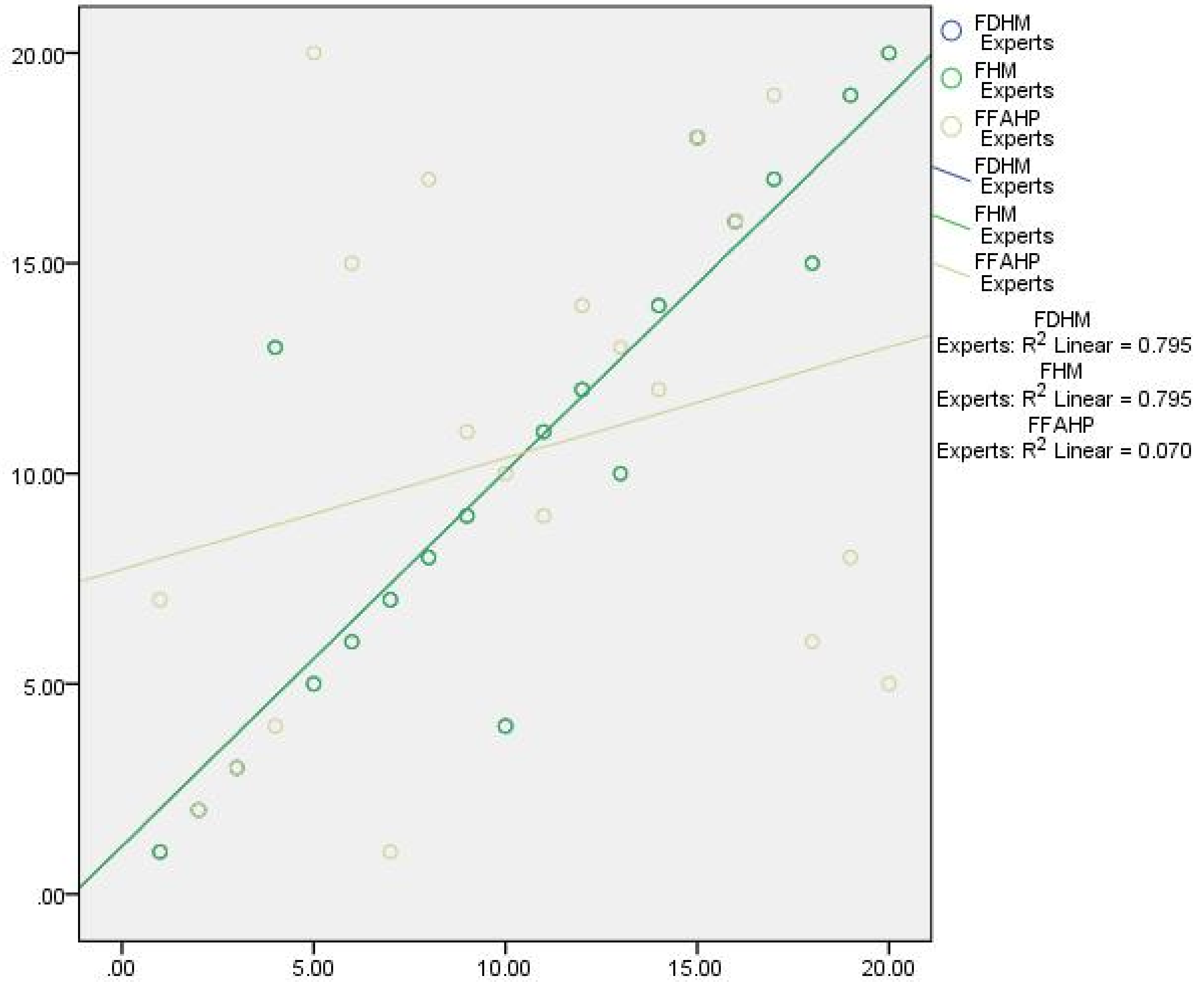


Figure 5.7: Correlation of FDHM, FFAHP and FHM with experts' DM

Table 5.13: Experiment 1, comparison of methods in accuracy and complexity

Accuracy			Complexity		
FDHM	FFAHP	FHM	FDHM	FFAHP	FHM
0.892	0.265	0.892	$O(m \cdot n)$	$O\left(m^2 \cdot n\right)$	$O(m \cdot n)$

$$TC_{FFAHP} = TC_{FAHP} = O\left(m^2 \cdot n\right)$$

The accuracy and TC of methods in this experiment are presented in table 5.13.

In this experiment FDHM and FHM had the same efficiency and more than FFAHP.

5.3.2 Expriment2: using FAHP for suppliers ranking

We select a decision making in MSC which leads to choose FAHP for evaluation of suppliers. The decision making is related to evaluation of Welding Wire-Electrodes

(WWE) suppliers. The environment of this DM is presented as:

- Re-ranking: 0.200
- Homogeny: 0.180
- Inconsistency: 0.170
- C-population: 7
- A-population: 20

The suitable method for alternative evaluating is determined based on FIS' results. THis experiment provides a set of input as [0.2 0.18 0.17 7 20] to prepare the conditions to select FAHP for supplier evaluation. According the considered input, the FIS generate the output as:

- FAHPI: 0.806
- FTOPSISI: 0.258

Figure 5.8 shows the rules which get involved in calculation of impacts through enter the considered input.

According the designed fuzzy MFs, when the impact is less than 0.32, it belongs to "very low" membership function and when the impact is greater than 0.68, it belongs to "very high" membership function (Refer section 4.5). Therefore, the FAHP as proper evaluation method is determined based on the following condition:

If FAHP impact is very high and FTOPSIS is very low,*then* FAHP method should be selected for evaluation of alternative.

The FDHM employs FAHP in stage of suppliers evaluation and ranking. Also the rankings are produced by FHM and FFAHP as well as experts' team. The results of ranking is presented in table 5.14.

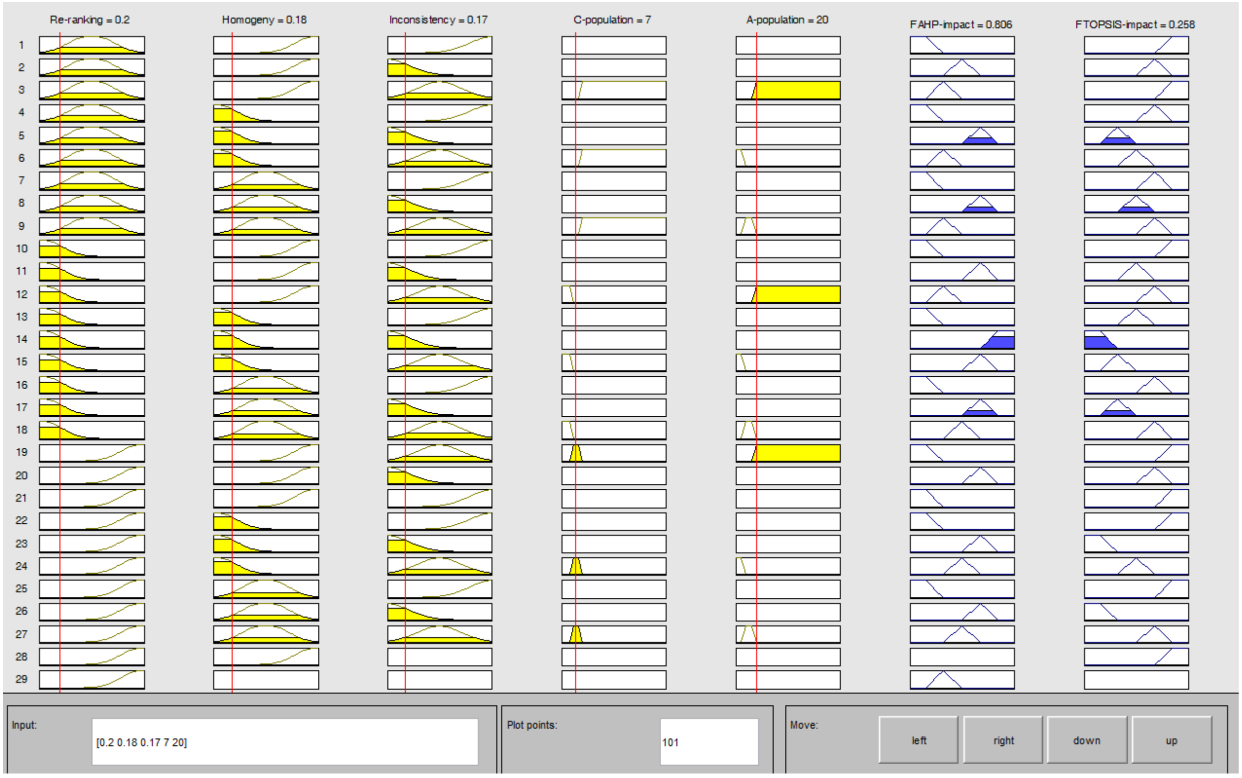


Figure 5.8: The rules' view of FIS with input[0.2 0.18 0.17 7 20]

Table 5.14: Experiment 2, suppliers' ranking

Rank	Experts' ranking	FHM' ranking	FFAHP' ranking	FDHM' ranking
1	S3	S4	S3	S3
2	S2	S14	S2	S2
3	S4	S3	S4	S4
4	S14	S2	S14	S14
5	S8	S12	S8	S8
6	S20	S17	S20	S20
7	S19	S19	S19	S19
8	S12	S8	S12	S12
9	S5	S1	S5	S5
10	S9	S20	S9	S9
11	S1	S7	S1	S1
12	S17	S5	S18	S18
13	S18	S18	S17	S17
14	S15	S15	S15	S15
15	S13	S6	S13	S13
16	S16	S16	S16	S16
17	S6	S9	S6	S6
18	S7	S10	S7	S7
19	S11	S11	S11	S11
20	S10	S13	S10	S10

The Pearson correlation coefficients (r-value), significance values (p-value), and the number of cases with non-missing values (N) of the method' rankings and experts' ranking is calculated and presented in table 5.15. The data is collected for 20 suppliers, so the value of N is 20.

The result of correlation analysis in table 5.13 shows that the ranking produced by FDHM method with $r-value = .998$ has very strong and linear relation with experts' ranking. The $p-value$ for FDHM is less than 0.01, so the correlation is significant at the 0.01 level.

The ranking produced by FFAHP method with $r-value = .998$ has very strong and linear relation with experts' ranking. The $p-value$ for FFAHP is less than 0.01, so the correlation is significant at the 0.01 level.

The ranking produced by FHM method with $r-value = .456$ has a linear relation with experts' ranking. The $p-value$ for FHM is less than 0.05, so the correlation is significant at the 0.05 level.

Table 5.15: Experiment 2, CC of methods' rankings with experts' ranking

method	Pearson CC (r-value)	p-value	Number of suppliers
FDHM	0.998	0.000	20
FHM	0.456	0.043	20
FFAHP	0.998	0.259	20

Figure (5.9) illustrates the difference in correlation between various methods' rankings and experts' ranking. The X axis is the experts' ranking and the Y axis is the methods' ranking. The FDHM and FFAHP have the same fit line.

The CC imply the accuracy of methods. So, FDHM and FFAHP have the same accuracy as well as the highest accuracy which caused by using same method for evaluation of suppliers.

In this experiment, the FFAHP and FDHM have the same process as FAHP is selected by FIS for evaluation of suppliers. Therefor, FFAHP and FDHM have the same TC. They have n comparison matrices corresponding to the number of criteria. In each matrix, the number of comparisons is $m \cdot m$. So, when the TC_x is the TC of x method and

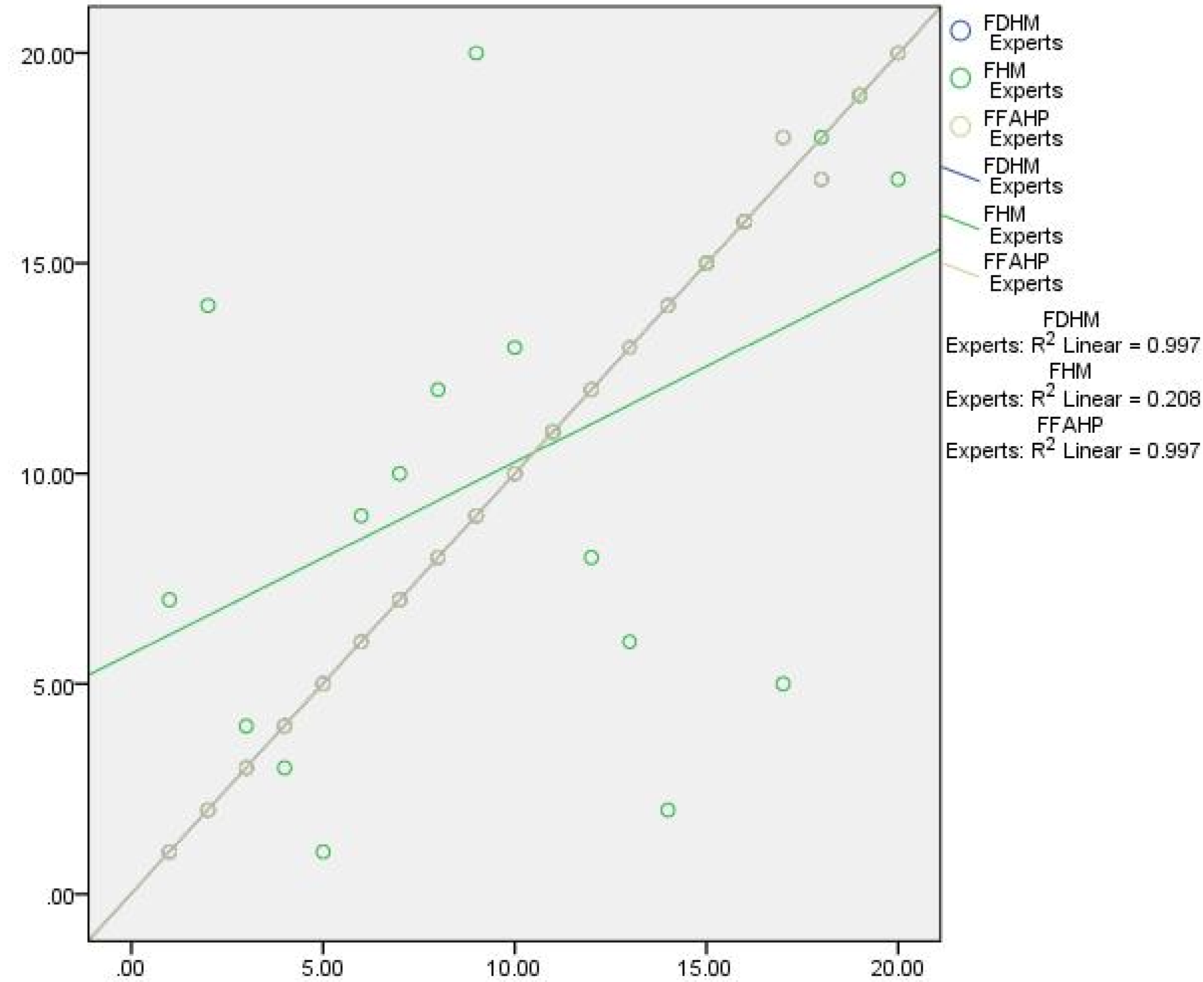


Figure 5.9: Correlation of FDHM, FFAHP and FHM with experts' DM

m is the number of suppliers and n is the number of criteria then:

$$TC_{FDHM} = TC_{FFAHP} = TC_{FAHP} = O\left(m^2 \cdot n\right)$$

FHM has one comparison matrix with m rows and n columns as n is the number of criteria and m is the number of suppliers. so:

$$TC_{FHM} = TC_{FTOPSIS} = O\left(m \cdot n\right)$$

The accuracy and TC of methods in this experiment are presented in table 5.16.

In this experiment FDHM and FFAHP have same efficiency and more than FHM.

Table 5.16: Experiment 1, comparison of methods in accuracy and complexity

Accuracy			Complexity		
FDHM	FFAHP	FHM	FDHM	FFAHP	FHM
0.998	0.998	0.456	$O\left(m^2 \cdot n\right)$	$O\left(m^2 \cdot n\right)$	$O(m \cdot n)$

5.3.3 Expriment3: using the combination of FAHP and FTOPSIS for suppliers ranking

We select a decision making in MSC which leads to choose combination of FAHP and FTOPSIS for evaluation of suppliers. The decision making is related to evaluation of chains' suppliers. The environment of this DM is presented as:

- Re-ranking: 0.500
- Homogeny: 0.500
- Inconsistency: 0.500
- C-population: 5
- A-population: 10

The suitable method for alternative evaluating is determined based on FIS' results. This experiment provides a set of input as [0.5 0.5 0.5 5 10] to prepare the conditions to determine the combination method for supplier evaluation. According the considered input, the FIS generate the output as:

- FAHPI: 0.
- FTOPSISI: 0.

Figure 5.10 shows the rules which get involved in calculation of impacts through enter the considered input.

According the designed fuzzy MFs, when the impact is less than 0.32, it belongs to "very low" membership function and when the impact is greater than 0.68, it belongs

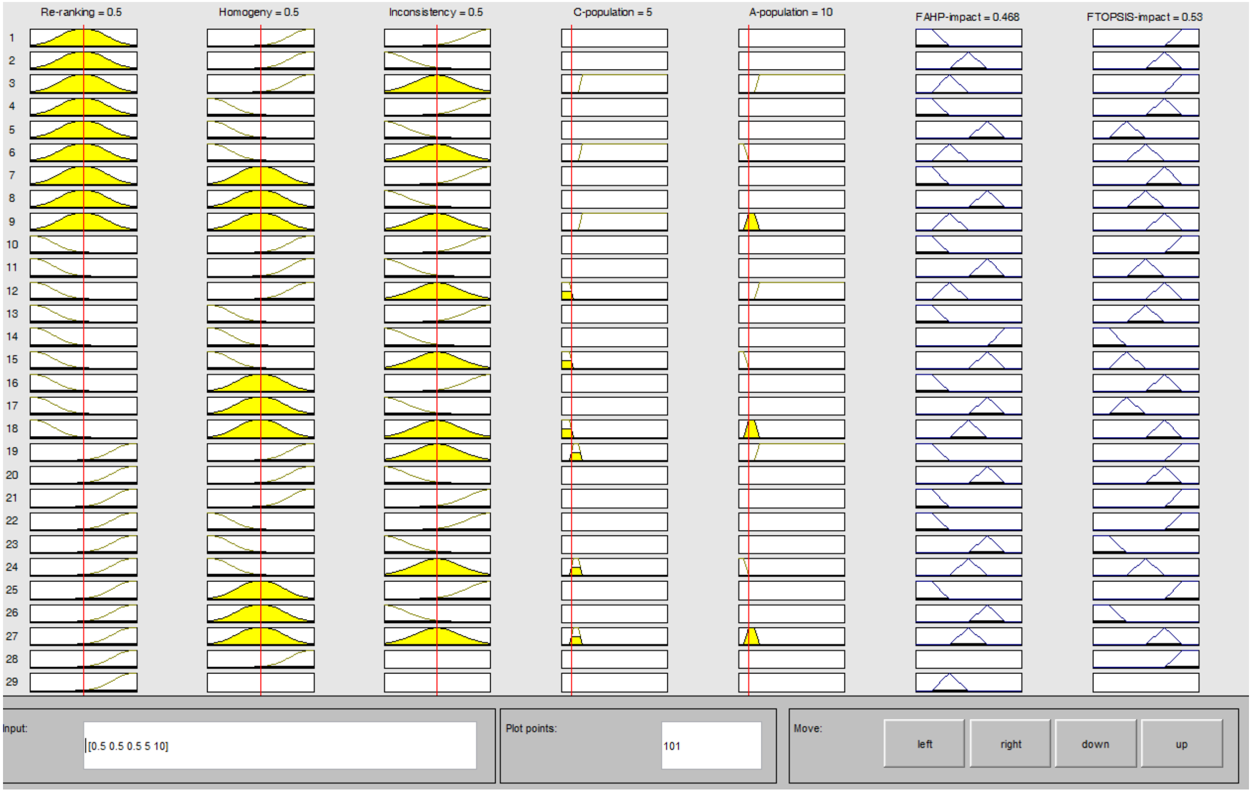


Figure 5.10: The rules' view of FIS with input[0.5 0.5 0.5 5 10]

to "very high" membership function (Refer section 4.5). Therefore, the combination of FTOPSIS and FAHP as proper evaluation method is determined based on the following condition:

- *If* FAHP impact is very low or FTOPSIS impact is very high, *then* FTOPSIS method should be selected for evaluation of alternative.
- *If* FAHP impact is very high and FTOPSIS is very low,*then* FAHP method should be selected for evaluation of alternative.
- The remainder conditions are combination conditions.

The FDHM employs the combination of FAHP and FTOPSIS in stage of suppliers evaluation and ranking. Under combination condition, the evaluation of alternatives is doing by both AHP and TOPSIS methods. Accordingly, we get two separate set of alternatives' weights. Then we combine the obtained weights based on methods' impacts (section 4.6). Also the rankings are produced by FHM and FFAHP as well as experts' team. The results of ranking is presented in table 5.17.

Table 5.17: Experiment 2, suppliers' ranking

Rank	Experts' ranking	FHM' ranking	FFAHP' ranking	FDHM' ranking
1	S2	S7	S2	S2
2	S6	S2	S6	S6
3	S7	S6	S3	S7
4	S3	S1	S7	S3
5	S1	S3	S4	S4
6	S4	S4	S1	S1
7	S10	S10	S10	S10
8	S9	S5	S9	S9
9	S5	S9	S5	S5
10	S8	S8	S8	S8

Table 5.18 displays Pearson correlation coefficients (r-value), significance values (p-value), and the number of cases with non-missing values (N) for correlation between methods' rankings and experts' ranking. The data is collected for 10 suppliers, so the value of N is 10.

The result of correlation analysis in table 5.3 shows that the ranking produced by FDHM method with $r-value = .891$ has very strong and linear relation with experts' ranking. The p-value for AHP is less than 0.01, so the correlation is significant at the 0.01 level.

For FHM $p-value = 0.138$, which is greater than 0.05. So, we are not confident that there is a correlation between FHM method' ranking and experts' ranking.

The FFAHP method' ranking with $r-value = .697$ has linear relation with experts' ranking. The p-value for FHM is less than 0.05, so the correlation is significant at the 0.05 level.

Table 5.18: CC of methods' rankings with experts' ranking

method	Pearson CC (r-value)	p-value	Number of cases
FDHM	0.891	0.001	10
FHM	0.503	0.138	10
FFAHP	0.697	0.025	10

The results shows that the produced ranking resulted by FDHM is closer than other methods' rankings to expert's ranking. Also, the FFAHP produced the second best ranking.

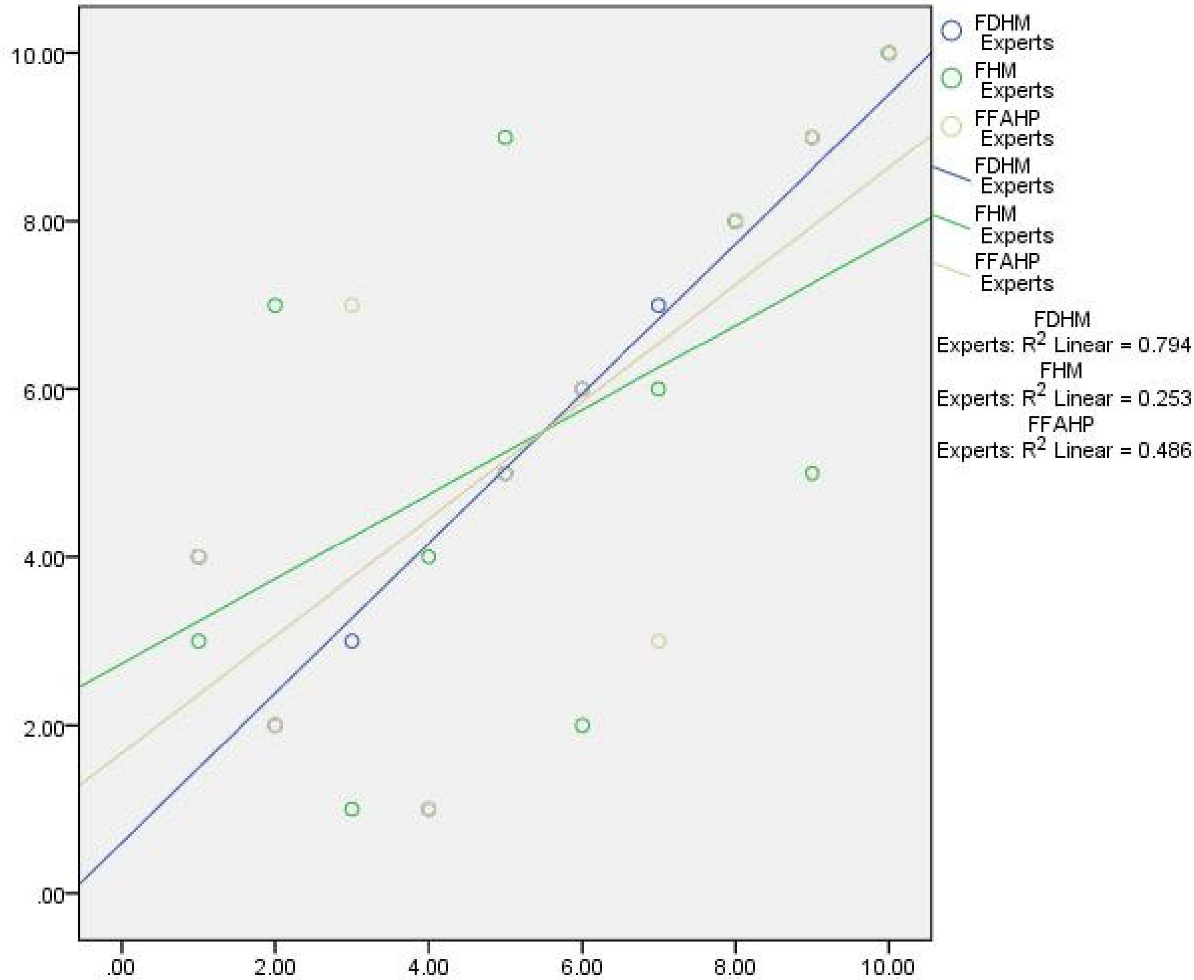


Figure 5.11: Correlation of FDHM, FFAHP and FHM with experts' DM

Figure (5.11) illustrates the difference in correlation between various methods' rankings and experts' ranking. The X axis is the experts' ranking and the Y axis is the methods' ranking. The FDHM has the better results to correlate with expert' ranking.

The CC imply the accuracy of methods. So, FDHM has the highest accuracy which caused by using combination method.

In this experiment, FDHM is the combination of FAHP and FTOPSIS. These methods are not combined together in form of nested. Therefore, we do not use the multiply operation to calculate the combination strategy' TC. We use the summation operator to

Table 5.19: Experiment 1, comparison of methods in accuracy and complexity

Accuracy			Complexity		
FDHM	FFAHP	FHM	FDHM	FFAHP	FHM
0.891	0.697	0.503	$O\left(m^2 \cdot n\right)$	$O\left(m^2 \cdot n\right)$	$O(m \cdot n)$

aggregate the methods' TCs. So, when the TC_x is the TC of x method and m is the number of suppliers and n is the number of criteria then:

$$TC_{FDHM} = TC_{FAHP} + TC_{FTOPSIS} = O\left(m^2 \cdot n\right) + O(m \cdot n) = O$$

$$= O\left(m^2 \cdot n\right) + O(m \cdot n) = O$$

$$= O\left(m^2 \cdot n\right)$$

The FFAHP has n comparison matrices corresponding to the number of criteria. In each matrix, the number of comparisons is $m \cdot m$, so:

$$TC_{FFAHP} = TC_{FAHP} = O\left(m^2 \cdot n\right)$$

FHM has one comparison matrix with m rows and n columns as n is the number of criteria and m is the number of suppliers, so:

$$TC_{FHM} = TC_{FTOPSIS} = O(m \cdot n)$$

The accuracy and TC of methods in this experiment are presented in table 5.19.

In this experiment FDHM has the higher efficiency than both FHM and FFAHP.

5.4 Summary

The various experiments for supplier management in Mobarakeh steel company is carried out. The experiments are in different DM environments. In each experiment, the rankings of method has compared with the rankings of current methods and statistical method based on the experts' opinion. The results are compared in terms of accuracy and time complexity. The method is more accurate and less complex in two experiments and it is more accurate and a bit more complex in one experiment. The overall performance of methods are presented in table 5.20.

Table 5.20: Performance of methods in accuracy and time complexity

Efficiency Factor	Accuracy			Time complexity		
method	FDHM	FFAHP	FHM	FDHM	FFAHP	FHM
Experiment 1	0.892	0.265	0.892	$O(m \cdot n)$	$O\left(m^2 \cdot n\right)$	$O(m \cdot n)$
Experiment 2	0.998	0.998	0.456	$O\left(m^2 \cdot n\right)$	$O\left(m^2 \cdot n\right)$	$O(m \cdot n)$
Experiment 3	0.891	0.697	0.503	$O\left(m^2 \cdot n\right)$	$O\left(m^2 \cdot n\right)$	$O(m \cdot n)$
Average	**0.927**	0.653	0.617	$O\left(\sqrt[3]{m^5 \cdot n^3}\right)$	$O\left(m^2 \cdot n\right)$	$O(m \cdot n)$

The results show that the accuracy of FDHM is more that other methods and the overall TC of FDHM is less than FFAHP and more than FHM. The accuracy is the first priority for mangers in using DSSs. Therefore, the FDHM is more efficient that other methods to use for supplier selection.

CHAPTER 6

CONCLUSION

6.1 Introduction

Supplier management is a DM problem in industrial management. It has a high influence on the overall efficiency of supply chain management. In supplier management, always more than one criterion should be considered and the situation of suppliers and DM is determined before decision. Therefore, it is a Multi-Attribiute Decision Making (MADM).

Decision makers who involve managers and experts insist on implementation of their opinion in DM method. The DM methods need to get information from experts so, they are dealing with uncertain information. The DMs are also complicated by the environment changes. Therefore, we considered three aspects to deal with DM about supplier management as multiple criteria, uncertainty and environment changes. The current SES methods do not address all these difficulties.

Most of MADMs have the same difficulties as supplier management. The designed decision method for supplier management is applicable to them.

6.2 Summary of dissertation

Based on existing methods of supplier management and the scope of research, the hybridization of AIBM and MCDM methods is determined as suitable methods to address SES.

The 207 ISI-indexed articles related to AIBM are selected and reviewed to identify suitable AI techniques and MCDM methods for SES. They involved 88 articles in FTs, 75 articles in EAs, 24 articles in ANNs, 11 articles in CBR and 9 articles in ES. The articles are analyzed in terms of year, citation, journal, author, applied AI techniques, how AI technique address MCDM, applied MCDM technique, hybridization type of AI and MCDM methods, application and conducted operations .

Since this study focus on FMCDM, the development of FMCDM is studied. The 142 ISI-indexed articles related to FMCDM are selected and reviewed. The articles are analyzed in terms of year, citation, journal, author, country ,applied fuzzy techniques, applied MCDM technique, application and conducted operations.

The environment of DM is defined and its elements are determined. The performance of candidate methods for supplier management (FAHP and FTOPSIS) are analyzed in different environments.

A fuzzy dynamic hybrid decision making method for Multi-Attribute Decision Makings(MADMs) specially supplier management is proposed.

The FDHM is used for managers in MSC in form of a research project (Appendix G). The various experiments for supplier management in Mobarakeh steel company is carried out to evaluate the satisfaction rate and efficiency of method. The experiments are in different DM environments. In each experiment, the rankings of method has compared with the rankings of current static method based on the experts' opinion. The results are compared in terms of accuracy and time complexity.

6.3 Summary of conducting operations, techniques and methods

Generally we can list the conducting operations, techniques and methods of this work as below:

1. Determination of the SES' views and the methods which carry out SES in those views.
2. Identification and classification the methods of applying AI techniques in MCDM.

3. Identification of the types of hybridization AI techniques and MCDM methods.
4. Identification of operations required to address supplier management.
5. Identification of candidate AI technique which is more suitable than other AI technique to address supplier management.
6. Identification and classification of fuzzy techniques applying in FMCDM.
7. Identification of candidate MCDM methods which are more suitable than other MCDM methods to address supplier management.
8. Identification of suitable hybridization type to hybrid the candidate methods for dealing with supplier management.
9. Definition of DM environment and related elements.
10. Identification of limitations of candidate methods in different environments.
11. proposing a Fuzzy Dynamic Hybrid MCDM method (FDHM) for supplier management.
12. Optimizing FDHM through implementing three strategies as dynamization based on DM environment, hybridization and DM fuzzification.
13. Definition of a new scale to fuzzify the linguistic variables of managers in supplier management.
14. Definition of fuzzy membership functions to diffuzzify the fuzzy values.
15. Design and Develop a Fuzzy Inference System (FIS) to determine the Alternative Evaluation Method.
16. Definition of numbers and intervals of membership functions for environment elements and method impacts.

17. Definition of a set of rules for FIS to inference the impacts numbers.
18. definition of a method for combination of FAHP and FTOPSIS rankings.
19. Determination of satisfaction rate in decision method.
20. Determination of accuracy in decision method.
21. Determination of time complexity in decision method.
22. Evaluation of FDHM .

6.4 Contributions

The main contributions of this work are:

1. Identify the candidate AI, MCDM and hybridization method to address supplier management.
2. Define the decision making environment and related elements.
3. Develop a Fuzzy Dynamic Hybrid MCDM method (FDHM) for supplier management.
4. Define a new scale to fuzzify the linguistic variables of managers in supplier management.
5. Design and Develop a Fuzzy Inference System (FIS) to determine the Alternative Evaluation Method.
6. Define a standard evaluation method for evaluation of decision making methods.

6.5 Interpretations of Results and Insights

The results of research are distributed between all chapters. In this section we summarize and interpret the results. We give our own insights regarding the obtained results.

6.5.1 Candidate AI based methods for supplier management

According to the scope of this research the hybrid methods with integration of LWM and AIBM are the best options to address SES. The multiple criteria view, highlights the MCDM methods among LWMs. The uncertainly highlights the AIBM methods. So, The methods of applying all AI techniques in MCDM are analyzed. The operations conducting by AI techniques in MCDM involve:

- Prediction
- Ranking
- Scheduling
- Selection
- Evaluation
- Optimization
- Assessment
- Allocation
- Comparison
- Planning
- Designing
- Classification
- Modeling

The suitability of a method is determined based on the matching the operations of DM and method. It is found that the supplier management operations are Evaluation, Ranking and Selection (ERS). The proper technique is the determined based on the addressing these operations.

The methods of applying EA in MCDM are classified to three groups:

1. The EAs is employed to solve MCDM problems. Multi-criterion quantum programming, Immune co-evolutionary algorithm are examples of these EAs.

2. The MCDM methods are applied to optimize EAs. In this group, the MCDM methods integrate with EAs to improve their performance in several steps. The MCDM methods are used to i) calculate fitness value or fitness function, ii) compare and evaluate individuals of population and change multiple criteria into one fitness value and iii) classify the chromosomes in population.

3. The EA and MCDM method address the DM in separate steps, such as i) the method uses MCDM methods before EA, to select one objective among multiple objectives. Therefore, the problem changes from multi objective optimization to single objective optimization and the GA solves new single objective optimization problem. ii) The method uses MCDM methods after EA, to select best solution among optimal solutions. These methods normally used Prato-optimal method.

The most combinations of EAs and MCDM are belong to "group 1". Also, "Prato-optimal" and "NSGA" are usual evolutionary techniques applying in MCDM. The ELECTREE and PROMOTEE as MCDM methods have more potential to collaborate with EAs. Often, the operations which is addresses by EA are optimization, planing, scheduling and modeling. So, EA is not a proper technique for supplier management.

The ANNs are directly applicable for some problems like prediction, pattern classification, associative memories optimization, vector quantization and control applications. The ANNs are suitable techniques for decision makings with incomplete and uncertain information. In this kind of DMs, NN has ability to complete the data using prediction and deal with uncertainty as well. There are four methods for applying ANNs in MCDMs:

1. Using ANN to solve MCDM problems. Here, the FFNN and MLP are more applicable than BPNN.

2. Use ANN to prepare a complete data set. This method is suitable for the DM problems with incomplete information and high level of inconsistency. In this method ANN is used to capture and represent decision maker's preferences. The ANNs get an example of preferences and then determine other preferences for decision making. The extension of this method is integration of ANN with MCDM methods. The ANN is used for representation of experts' knowledge and MCDM methods for evaluation of alternatives.

3. The Output of ANN technique considers as a criteria in decision making problem and MCDM methods apply to evaluate alternatives. In this group there are different integration of ANN and MCDM methods such as BPNN and TOPSIS.

4. Using MCDM techniques for evaluation and selection of the best ANN technique for a special application.

The usual method of applying ANN in MCDM is belong to "group 3" where the output of ANN technique considers as the criteria in decision making problem and MCDM methods apply to solve problem.

In supplier management the information of suppliers are complete and we do not need to represent experts' opinion. Often, the decision making with operations of designing, prediction, optimization and classification are carried out by ANN.

The CBR as an AI technique is suitable for decision makings with the similar decision making cases. The extension of this method is integration of CBR with MCDM methods such AHP to speed in the process of case matching and increase the accuracy. CBR technique is suitable for decision makings which they have similar decision cases. I supplier management the DMs are totally different from each other. Therefore, CBR is not a proper technique for supplier management.

Expert system is applied to use its knowledge base to keep expert's knowledge and MCDM rules. Also its inference engine is used for rational and making decision like human inferences. expert system is proper for DMs with the static criteria and environment. Therefore, considering the environment change it is not applicable for supplier management.

The supplier management operations are Evaluation, Ranking and Selection (ERS). Based on the abilities of the AI techniques and SES requirements the FTs are the candidate AI techniques for supplier management. The correlate differences between AI techniques and ERS shows that the conducting ERS in FTs' articles has a strongest linear relation with the number of articles in FTs. Also, uncertainty is One of the important factors which is addressed by FTs.

The differing FTs such as alpha-cut, Intuitionistic fuzzy sets, TFN, TPFN and 2-type fuzzy sets have been applied for MCDMs. Since defuzzification of linguistic variables for input of MCDM methods is an important issue in MCDM. TFN uses three numbers and TPFN uses four numbers to fuzzify linguistic variable. Therefor, using TPFN in MCDM with various criteria, decision makers and alternatives causes to high range of computations. TFN is faster than TPFN as well as it has higher CC with ERS.

We identify the Fuzzy AHP and TOPSIS method as candidate methods for SES. The most suitable AI and MCDM methods which can fulfill the SES requirements are FTs, AHP and TOPSIS methods. The best hybridization type of FTs with AHP and TOPSIS is integration of FTs with AHP and TOPSIS.

6.5.2 FIS rules and MFs

The performance of candidate decision methods are effected by the environment changes. For different environments the suitable decision method is employed. The accuracy of a decision making method is depended to work based on the DM situations.

FAHP and FTOPSIS do not working well in all situations. Therefore, individually using of FAHP and FTOPSIS reduces the accuracy. Integrating these methods caused to switch between methods when in a specific situation one of them has limitation.

The FIS is developed to determine the evaluation method. The situation of environment is the input of the FIS. The environment situation is presented by five elements. The different fuzzy MFs is defined to measure the different elements. The FAHPI and FTOPSISI also are measured by fuzzy MFs. The reasons to defined the different MFs for inputs/outputs are as below:

Inconsistency, homogenous and re-ranking are *pure fuzzy inputs* which are evaluated completely based on experts' opinion and through fuzzy variables. Therefore, we select Gaussian membership functions to obtain accuracy in defuzziffication values of these situations. A-population and C-population are fuzzy inputs which are evaluated based on experts' opinion and their numerical values. A-Population is number of alternative and C-population is number criteria which experts' opinions are used to define their membership functions. Therefore, three trapezoidal membership functions are defined for A-populationas situation.

The FIS rules are designed according the attributes of methods in different conditions. The DM environments' elements are the facts in FIS which are changeable in different DMs. However, the determined rules are constant for any environments and conditions.

These rules determines the mechanism of environment' effectiveness on methods' impact. When the FIS receives the inputs, the inputs fill the "if" parts of rules and the "then" parts be aggregated and defuzzified to obtain the final FAHPI and FTOPSISI.

The performance of rules to generate output is presented thorough the surface view of rules as:

- Increasing homogeny and re-ranking in DM causes to increase the FTOPSIS impact.
- Increasing homogeny and inconsistency in DM causes to increase the FTOPSIS impact.
- Increasing re-ranking and inconsistency in DM causes to increase the FTOPSIS impact.
- Decreasing homogeny and re-ranking in DM causes to decrease the FAHP impact.
- Decreasing homogeny and inconsistency in DM causes to decrease the FAHP impact.
- Decreasing re-ranking and inconsistency in DM causes to decrease the FAHP impact.

The results confirmed the compliance of rules and attributes of methods. the FIS fulfills the expectations about selection the proper method according the environment.

6.5.3 Evaluation results

We investigate the relation between FDHM' ranking and experts' ranking through the calculation of their correlation coefficient. The reason to use experts for evaluation is that the best decision making method is the closer one to experts' decision analysis. Therefore, the satisfaction of experts from a decision making method is a guaranty for that.

The FDHM method' ranking has very strong linear relation with experts' ranking. The results showed that the produced ranking resulted by FDHM is equal to expert's ranking. The ability of method to handle the evaluation and to produce a ranking in high correlation coefficient with experts' ranking, implied the *satisfactorily* of method to address supplier management. In this case, FDHM has achieved to the complete satisfaction of experts.

In experiment 1, The FDHM and FHM have the same accuracy and TC. They have the highest accuracy which caused by using same method for evaluation of suppliers. In this experiment the FTOPSIS is selected by FIS for evaluation of suppliers. Therefor, FHM and FDHM have the same efficiency and more than FFAHP.

In experiment 2, The FDHM and FFAHP have the same accuracy and TC which is caused by the using the same method(FAHP) for evaluation of suppliers. Their accuracy is much more than the FHM and their TC is higher than FHM. However, they are more efficient than FHM since, the accuracy has a higher priority to evaluate effiency of a DM method.

In experiment 3, The accuracy of FDHM is higher than FHM and FFAHP. The reason to get this result is the combination of FAHP and FTOPSIS rankings with regard to their impact factors. The TC of FDHM in this experiment is equal to FFAHP and it has the higher TC in compare with FHM.

The method is more accurate and less complex in two experiments and it is more accurate and a bit more complex in one experiment. In general, the TC of FHM is lower than FDHM. However the accuracy of FDHM is higher than FHM. The TC of FFAHP is higher than FDHM and its accuracy is lower than FDHM. Therefore, in terms of accuracy the FDHM is the first method and in terms of TC, the FHM is the first method and FDHM is the second method. Considering that the managers insist on accuracy of a DM more than its TC. Therefore, the FDHM can meet their expectations.

6.6 Limitation of work

This study overcomes the limitation of FAHP and FTOPSIS using switching between methods. When in a situation FAHP is not able to produce answer then the method choose FTOPSIS to continue the evaluation of suppliers. However, their problem in aforementioned cases still are remained. FAHP has limitation with large number of alternatives and criteria. This method can not deal with adding alternative and criteria and re-ranking. Also when the inconsistency is high and we reach to a high inconsistency ratio then the FAHP completely is failed.

When the alternatives are specialist the FTOPSIS is not able to produce ranking. We have proved this limitation using an experiment in chapter 3. Also when there are a few number of alternatives and criteria, this method does not produced accurate result.

The aforementioned limitations of methods are discussed during chapter 3 and 5. This study proposed a method just to escape this limitations. However, the future work can solve these problems by other techniques.

We had limitation to evaluate method in a DM with a high number of criteria and suppliers. Because the human had been asked to carry out the same job as FDHM. The experts are not able to evaluate a large number of suppliers.

6.7 Recommendations for Future works

The future work would be involved the MODMs. The method has potential to extend for all DMs. In this case, the environment of MODMs and the manner of various MODM methods will be studied. The the environment' elements can be extended. Accordingly, the new rules with regard to the attributes of all MODM methods will be designed. This can be performed by analyzing their limitations and applications in different situations of environment.

Also, the future work can solve the limitations of FAHP and FTOPSIS methods may using mathematical or intelligence methods.

6.8 Conclusion remarks

The supplier management problem is an industrial management issue and has a high influence on the overall efficiency of supply chain management. Various purchases have to carried out in a company. This leads to a dynamic environment with different situations. Therefore, an efficient evaluation method is necessary to improve supplier management.

We analyzed the intelligent MCDM methods. The results show that the integration of AHP and TOPSIS under fuzzy environment is proper for supplier management.

We proposed a dynamic method to evaluate the suppliers, by developing a FIS to deal with the dynamic changes of the decision environment. We fuzzyfied AHP and TOPSIS methods to deal with the uncertain data and environment.

The proposed method has significantly increased the efficiency of the decision making process. The FAHP method has a good performance for weighting of large or small number of criteria. The FIS works as a controller to find a proper way to continue the evaluation. When FIS selects the FTOPSIS method for supplier evaluation, TOPSIS does not construct pairwise comparison matrices as performed in Fuzzy AHP that saves processing time. When FTOPSIS is unable to create accurate results, FIS selects FAHP for supplier evaluation that increase accuracy. Sometimes FIS recommends the combination of FAHP and FTOPSIS results which does not minimize the time but maximizes the accuracy of evaluation. Additionally, it is shown that considering decision making situations makes the evaluation and selection more effective.

The proposed method can also be used for other discrete DMs. The proposed FIS can be developed for continuous DM problems. This can be performed by analyzing other MCDM methods, their limitations and applications in a broader defined environment.

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Appendix A

Dataset of articles related to hybridization of EA and MCDM

Article#	Group#			Technique					
	1	2	3	Prato-optimal	MCQP	ICEA	NSGA	ELECTRE	POMETHEE
[1]			✓	*					
[2]			✓						
[3]	✓								
[4]	✓				*				
[5]	✓				*				
[6]			✓					*	
[7]			✓						
[8]		✓							
[9]		✓							
[10]	✓								
[11]		✓							*
[12]	✓					*			
[13]	✓								
[14]			✓						
[15]		✓							*
[16]			✓						
[17]			✓				*	*	
[18]	✓								
[19]	✓						*		
[20]	✓						*		

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11. De Lit, P., et al., *Assembly planning with an ordering genetic algorithm.* International Journal of Production Research, 2001. **39**(16): p. 3623-3640.
12. Ding, Y.-S., Z.-H. Hu, and W.-B. Zhang, *Multi-criteria decision making approach based on immune co-evolutionary algorithm with application to garment matching problem.* Expert Systems with Applications, 2011. **38**(8): p. 10377-10383.
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14. Guo, C.X., J.P. Zhan, and Q.H. Wu, *Dynamic economic emission dispatch based on group search optimizer with multiple producers.* Electric Power Systems Research, 2012. **86**: p. 8-16.
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Appendix B

Dataset of articles related to FMCDM

Article			**Operation**			**Fuzzy numbers**		**fuzzy methods**		
Article Title	**year**	**Author**	**Ranking**	**selection**	**evaluation**	**TFN**	**TPFN**	**alpha-cut**	**Intuitionistic**	**2-tuple**
A fuzzy decision support system for digital camera selection based on user preferences	2012	Alptekin SE		1	1	1				
An integrated fuzzy model for supplier management: A case study of ISP selection and evaluation	2009	Amin, S. H. and J. Razmi		1	1	1				
Supplier selection and order allocation based on fuzzy SWOT analysis and fuzzy linear programming	2011	Amin, S. H. and J. Razmi		1		1				
A hybrid multi-criteria decision-making model for firms competence evaluation	2009	Amiri, M., M. Zandieh			1		1	1		
A decision support system for coating selection based on fuzzy logic and multi-criteria decision making	2009	Athanasopoulos, G., C. Romeva Riba		1						
Deriving preference order of open pit mines equipment through MADM methods: Application of modified VIKOR method	2011	Bazzazi, Abbas Aghajani Osanloo, Morteza Karimi, Behrooz	1	1	1					
A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method	2009	Boran, Fatih Emre		1					1	
Logistics tool selection with two-phase fuzzy multi criteria decision making: A case study for personal digital assistant selection	2012	Buyukozkan, G., J. Arsenyan		1	1					
A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers	2012	Buyukozkan, Gulcin Cifci, Gizem			1					
Choquet integral based aggregation approach to software development risk assessment	2010	Buyukozkan, Gulcin Ruan, Da		1	1					
A web-based decision support system for multi-criteria inventory classification using fuzzy AHP methodology	2008	Cakir, Ozan Canbolat	1							

Fuzzy AHP-based decision support system for selecting ERP systems in textile industry by using balanced scorecard	2009	Cebeci, Ufuk		1	1					
A fuzzy case-based reasoning model for sales forecasting in print circuit board industries	2008	Chang, Pei-Chann Liu, Chen-Hao Lai, Robert K.				1				
Using the fuzzy multi-criteria decision making approach for measuring the possibility of successful knowledge management	2009	Chang, Tsung-Han Wang, Tien-Chin		1	1	1				
An integrated fuzzy approach for the selection of outsourcing manufacturing partners in pharmaceutical R & D	2010	Chen, L.-H. and C.-C. Hung		1						
A comparative analysis of score functions for multiple criteria decision making in intuitionistic fuzzy settings	2011	Chen, Ting-Yu								
Supplier selection using consistent fuzzy preference relations	2012	Chen, Ting-Yu		1						
ASA and its application to multi-criteria decision making	2000	Choi, D. Y.								
Evaluating IT/IS investments: A fuzzy multi-criteria decision model approach	2006	Chou, Tzy-Yuan Chou			1					
Partner selection in virtual enterprises: a multi-criteria decision support approach	2009	Crispim, Jose Antonio de Sousa,		1	1					
Partner selection in virtual enterprises	2010	Crispim, J. A. and J. P. de Sousa		1	1					
Weapon selection using the AHP and TOPSIS methods under fuzzy environment	2009	Dagdeviren, Metin		1	1					
Developing a fuzzy analytic hierarchy process (AHP) model for behavior-based safety management	2008	Dagdeviren, MetinYueksel, Ihsan	1		1	1				
A fuzzy logic approach to the selection of the best silicon crystal slicing technology	2009	Dalalah, Doraid Bataineh, Omar		1						
A fuzzy multi-criteria decision making model for supplier selection	2011	Dalalah, Doraid Hayajneh,	1	1	1					
A new fuzzy dempster MCDM method and its application in supplier selection	2011	Deng, Yong Chan, Felix T. S.		1		1				

Extension of VIKOR method in intuitionistic fuzzy environment for robot selection	2011	Devi, Kavita		1		1			1	
Multi-criteria decision aid for the formulation of sustainable technological energy priorities using linguistic variables	2007	Doukas, Haris Ch Andreas, Botsikas M. Psarras, John E.	1							
On the use of aggregation operations in information fusion processes	2004	Dubois, D. Prade, H.								
A fuzzy MCDM approach for personnel selection	2010	Dursun, Mehtap Karsak, E. Ertugrul		1		1				1
A fuzzy multi-criteria group decision making framework for evaluating health-care waste disposal alternatives	2011	Dursun, Mehtap Karsak,			1	1				
Fuzzy multi-criteria analysis approach for the evaluation and classification of cognitive performance factors in flexible manufacturing systems	2007	Eraslan, E. Kurt, M.	1		1	1				
Performance evaluation of Turkish cement firms with fuzzy analytic hierarchy process and TOPSIS methods	2009	Ertugrul, Irfan Karakas oglu, Nilsen	1		1	1				
A fuzzy optimization method for multicriteria decision making: An application to reservoir flood control operation	2008	Fu, Guangta o	1		1	1				
Fuzzy outranking for environmental assessment. Case study: iron and steel making industry	2000	Gelderm ann, J. Spengler , T. Rentz, O.	1		1		1			
A new integrated design concept evaluation approach based on vague sets	2010	Geng, Xiuli Chu, Xuening Zhang, Zaifang			1					
Shaft location selection at deep multiple orebody deposit by using fuzzy TOPSIS method and network optimization	2010	Gligoric, Zoran Beljic, Cedomir Simeuno vic, Veljko		1	1	1				
A consistency test for rational weights in multi-criterion decision analysis with fuzzy pairwise comparisons	1997	Gogus, O. Boucher, T. O				1				
An extension of the PROMETHEE method for decision making in fuzzy environment: Ranking of alternative energy exploitation projects	2000	Goumas, M. Lygerou, V.	1		1	1				
A review of methods for capacity identification in Choquet integral based multi-attribute utility theory	2008	Grabisch , Michel Kojadin	1							

applications of the Kappalab R package		ovic, Ivan Meyer, Patrick								
A fuzzy ANP approach to shipyard location selection	2009	Guneri, A. F. Cengiz, M. Seker, S.		1						
An approach based on ANFIS input selection and modeling for supplier selection problem	2011	Guneri, Ali Fuat Ertay, Tijen Yucel, Atakan		1	1					
Asset portfolio optimization using fuzzy mathematical programming	2008	Gupta, Pankaj Mehlaw at, Mukesh Kumar Saxena, Anand		1						
A hybrid approach to asset allocation with simultaneous consideration of suitability and optimality	2010	Gupta, Pankaj Mehlaw at, Mukesh Kumar Saxena, Anand		1						
Linguistic decision analysis: steps for solving decision problems under linguistic information	2000	Herrera, F.Herrer a-Viedma, E	1	1		1	1			
Solving multi-criteria decision making with incomplete linguistic preference relations	2011	Hsu, Shu-Chen Wang, Tien-Chin								
Fuzzy preference based rough sets	2010	Hu, Qinghua Yu, DarenGu o, Maozu	1							
Fuzzy concepts in radiotherapy	2000	Hussein, M. L. Ahmed, E.			1	1				
Development of a decision support system for machining center selection	2009	Ic, Yusuf Tansel Yurdaku l, Mustafa	1	1						
Selection of new production facilities with the Group Analytic Hierarchy Process Ordering method	2011	Ishizaka, Alessio Labib, Ashraf	1	1						
Supplier selection using fuzzy association rules mining approach	2007	Jain, V. Wadhwa , S. Deshmu kh, S. G.		1						

Emergency alternative evaluation under group decision makers: A method of incorporating DS/AHP with extended TOPSIS	2012	Ju, Yanbing Wang, Aihua		1						
A fuzzy hybrid MCDM approach for professional selection	2012	Kabak, Mehmet Burmaoglu, Serhat Kazancoglu, Yigit		1		1				
Selection among ERP outsourcing alternatives using a fuzzy multi-criteria decision making methodology	2010	Kahraman, Cengiz Beskese, Ahmet Kaya, Ihsan		1						
Robot selection using an integrated approach based on quality function deployment and fuzzy regression	2008	Karsak, E. Ertugrul								
A new TOPSIS-based multi-criteria approach to personnel selection	2010	Kelemenis, Alecos Askounis, Dimitrios	1	1		1	1			
The Fuzzy ART algorithm: A categorization method for supplier evaluation and selection	2010	Keskin, Guelsen Aydin Ilhan, Sevinc Ozkan, Coskun	1	1						
Facility layout problem: an approach based on a group decision-making system and psychoclonal algorithm	2008	Khilwani, N. Shankar, R. Tiwari, M. K.			1					
Fuzzy AHP approach for supplier selection in a washing machine company	2011	Kilincci, Ozcan Onal, Suzan Ash		1						
Minimum variance capacity identification	2007	Kojadinovic, Ivan								
Multi-Criteria Decision Making support system for pancreatic islet transplantation	2011	La Scalia, Giada Aiello, Giuseppe Rastellini, Cristiana Micale, Rosa Cicalese, Luca				1				
A dynamic approach to multiple-objective resource allocation problem	1999	Lai, K. K. Li, L. S.								

Evaluation of new service concepts using rough set theory and group analytic hierarchy process	2012	Lee, Changyong Lee, Hakyeon Seol, Hyeonju Park, Yongtae		1	1					
Optimal consensus of fuzzy opinions under group decision making environment	2002	Lee, H. S.					1			
A fuzzy-based decision-making procedure for data warehouse system selection	2007	Lin, Hua-Yang Hsu, Ping-Yu Sheen, Gwo-Ji		1		1				
Multi-criteria decision-making methods based on intuitionistic fuzzy sets	2007	Liu, Hua-Wen Wang, Guo-Jun			1				1	
An agent-oriented decision support system combining fuzzy clustering and the AHP	2011	Lopez-Ortega, Omar Rosales, Marco-Antonio			1					
A fuzzy multi-criteria model for the industrial cooperation program transaction strategies: A case in Taiwan	2011	Lu, Wen-Min Wang, Tsung-Cheng			1	1				
A TFN-ANP based approach to evaluate Virtual Research Center comprehensive performance	2010	Luo, Zhi-meng Zhou, Jian-zhong Zheng	1		1	1				
Multi-objective fuzzy inventory model with three constraints: a geometric programming approach	2005	Mandal, N. K. Roy, T. K. Maiti, M.								
k-intolerant capacities and Choquet integrals	2007	Marichal, Jean-Luc								
Tolerant or intolerant character of interacting criteria in aggregation by the Choquet integral	2004	Marichal, J. L.								
Proactive, dynamic and multi-criteria scheduling of maintenance activities	2009	Marmier, F. Varnier, C. Zerhouni, N.		1						
Methods for decision making with cardinal numbers and additive aggregation	1997	Meier, K.	1	1	1					
Ranking fuzzy numbers by preference ratio	2001	Modarres, M. Sadi-Nezhad,	1		1	1				

		S								
The use of multi-criteria data envelopment analysis (MCDEA) for location-allocation problems in a fuzzy environment	2011	Moheb-Alizadeh, H. Rasouli, S. M. Tavakkoli-Moghaddam, R.		1						
Intelligent systems for engineering design and configuration problems	1997	Muller, K. Sebastian, H. J.		1	1	1	1			
The application of fuzzy analytic hierarchy process (FAHP) approach to selection of optimum underground mining method for Jajarm Bauxite Mine, Iran	2009	Naghadehi, Masoud Zare Mikaeil, Reza Ataei, Mohammad	1	1	1	1				
Multi-criteria decision-making method based on interval-valued intuitionistic fuzzy sets	2011	Nayagam, V. Lakshmana Gomathi Muralikrishnan,	1						1	
A soft multi-criteria decision-making approach to assessing the goodness of typical reasoning systems based on empirical data	2002	Niskanen, V. A.			1					
Fuzzy decision support system for crisis management with a new structure for decision making	2010	Nokhbatolfoghahaayee, Hoda Menhaj, Mohammad Bagher Shafiee, Masoud	1	1						
A combined fuzzy MCDM approach for selecting shopping center site: An example from Istanbul, Turkey	2010	Oenuet, Semih Efendigil, Tugba Kara, Selin Soner		1	1	1				
Long term supplier selection using a combined fuzzy MCDM approach: A case study for a telecommunication company	2009	Oenuet, Semih Kara, Selin Soner Isik, Elif		1	1	1				
A fuzzy assessment framework to select among transportation investment projects in Turkey	2012	Ozkir, Vildan Demirel, Tufan		1	1	1				
A compensatory fuzzy approach to multi-objective linear supplier selection problem with multiple-item	2011	Ozkok, Beyza Ahlatcioglu Tiryaki, Fatma		1						

A fuzzy analytic hierarchy processing decision support system to analyze occupational menace forecasting the spawning of shoulder and neck pain	2011	Padma, T. Balasubramanie, P.				1				
A case retrieval method combined with similarity measurement and multi-criteria decision making for concurrent design	2009	Qi, Jin Hu, Jie Peng, Ying-Hong Wang, Weiming Zhang, Zhenfei		1	1	1	1			
Optimal restoration of stochastic monotonicity with respect to cumulative label frequency loss functions	2011	Rademaker, M. De Baets, B.								
Ranking multi-criterion river basin planning alternatives using fuzzy numbers	1998	Raj, P. A. Kumar, D. N	1		1		1			
A rule-based multi-criteria approach to inventory classification	2010	Rezaei, Jafar Dowlatshahi, Shad	1							
Probability density functions based weights for ordered weighted averaging (OWA) operators: An example of water quality indices	2007	Sadiq, Rehan Tesfamariam, Solomon			1					
Group decision making process for supplier selection with VIKOR under fuzzy environment	2010	Sanayei, Amir Mousavi, S. Farid Yazdankhah, A.		1	1		1			
Integration of closed loop distribution supply chain network and 3PRLP selection for the case of battery recycling	2011	Sasikumar, P. Haq, A. Noorul		1						
Fuzzy performance evaluation in Turkish Banking Sector using Analytic Hierarchy Process and TOPSIS	2009	Secme, Nese Yalcin Bayrakdaroglu, Ali Kahraman, Cengiz	1		1	1				
An integrated decision support system dealing with qualitative and quantitative objectives for enterprise software selection	2009	Sen, Ceyda GuengoerBarach, HayriSen, SelcukBasligil, Hueseyin		1	1	1				
Pre-selection of suppliers through an integrated fuzzy analytic hierarchy process and max-min methodology	2010	Sen, Ceyda Guengoer Barach, Hayri Sen,		1						

		Selcuk Basligil, Hueseyin								
An application of the fuzzy ELECTRE method for supplier selection	2010	Sevkli, Mehmet		1						
Development of a fuzzy ANP based SWOT analysis for the airline industry in Turkey	2012	Sevkli, Mehmet Oztekin, Asil Uysal, Ozgur Torlak, Gokhan Turkyilmaz, Ali Delen, Dursun	1							
A hybrid neuro-fuzzy analytical approach to mode choice of global logistics management	2008	Sheu, Jiuh-Biing		1		1				
Optimization of logistic systems using fuzzy weighted aggregation	2007	Silva, C. A. Sousa, J. M. C. Runkler, T. A			1					
Justification for the selection of a reconfigurable manufacturing system: a fuzzy analytical hierarchy based approach	2007	Singh, R. K. Khilwani, Nitesh Tiwari, M. K.		1	1	1				
Lean tool selection in a die casting unit: a fuzzy-based decision support heuristic	2006	Singh, R. K. Kumar, S. Choudhury, A. K. Tiwari, M. K.	1	1	1	1				
A multi-criteria interval-valued intuitionistic fuzzy group decision making with Choquet integral-based TOPSIS	2011	Tan, Chunqiao			1				1	
Intuitionistic fuzzy Choquet integral operator for multi-criteria decision making	2010	Tan, Chunqiao Chen, Xiaohong			1				1	
An integrated fuzzy multi-criteria decision making methodology for material handling equipment selection problem and an application	2010	Tuzkaya, Guelfem Gulsun, Bahadir Kahraman, Cengiz Ozgen, Dogan		1	1	1				
FUZZY MULTICRITERIA ANALYSIS OF CUTTING TECHNIQUES IN A NUCLEAR-REACTOR DISMANTLING PROJECT	1995	Vandewalle, B. Debaets, B. Kerre, E. E.						1		

Fuzzy programming technique to solve multi-objective transportation problems with some non-linear membership functions	1997	Verma, R. Biswal, M. P. Biswas, A.								
Application of fuzzy analytic network process for agile concept selection in a manufacturing organisation	2010	Vinodh, S. Gautham, S. G. Ramiya, R. Anesh Rajanayagam, D.		1						
Integration of fuzzy AHP and FPP with TOPSIS methodology for aeroengine health assessment	2010	Wang, Jianrong Fan, Kai Wang, Wanshan			1		1			
A fuzzy hybrid decision-aid model for selecting partners in the design chain	2006	Wang, J. Lin, H. Y.		1	1		1	1		
Multi-criteria fuzzy decision-making method based on cross entropy and score functions	2011	Wang, Jian-qiang Li, Jing-jing	1		1				1	
A fuzzy multicriteria group decision making approach to select configuration items for software development	2003	Wang, J. T. Lin, Y. I.	1	1		1				
Application of TOPSIS in evaluating initial training aircraft under a fuzzy environment	2007	Wang, Tien-Chin Chang, Tsung-Han			1	1				
Fuzzy multi-criteria selection among transportation companies with fuzzy linguistic preference relations	2011	Wang, Tien-Chin Chen, Ying-Hsiu	1	1						
Applying the consistent fuzzy preference relations to select merger strategy for commercial banks in new financial environments	2009	Wang, Tien-Chin Lin, Ying-Ling		1						
Accurately predicting the success of B2B e-commerce in small and medium enterprises	2009	Wang, Tien-Chin Lin, Ying-Ling								
Applying FMCDM to evaluate financial performance of domestic airlines in Taiwan	2008	Wang, Yu-Jie			1					
Combining grey relation analysis with FMCGDM to evaluate financial performance of Taiwan container lines	2009	Wang, Yu-Jie			1					
Evaluating alternative production cycles using the extended fuzzy AHP method	1997	Weck, M.Klocke, F.Schell, H.Ruena	1		1					

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A new approach for selecting portfolio of new product development projects	2011	Wei, Chiu-Chi Chang, Houn-Wen		1						
Entropy, similarity measure of interval-valued intuitionistic fuzzy sets and their applications	2011	Wei, Cui-Ping Wang, Pei Zhang, Yu-Zhong							1	
A fashion mix-and-match expert system for fashion retailers using fuzzy screening approach	2009	Wong, W. K. Zeng, X. H. Au, W. M. R. Mok, P. Y. Leung, S. Y. S.								
Selecting the preferable bancassurance alliance strategic by using expert group decision technique	2009	Wu, Cheng-Ru Lin, Chin-Tsai Lin, Yu-Fan		1	1					
The ELECTRE multicriteria analysis approach based on Atanassov's intuitionistic fuzzy sets	2011	Wu, Ming-Che Chen, Ting-Yu	1						1	
CONNECTIVES AND QUANTIFIERS IN FUZZY-SETS	1991	Yager, R. R.								
Application of fuzzy multi-criteria decision making methods for financial performance evaluation of Turkish manufacturing industries	2012	Yalcin, Nese Bayrakdaroglu, Ali Kahraman, Cengiz	1		1					
On prioritized weighted aggregation in multi-criteria decision making	2011	Yan, Hong-Bin Huynh, Van-Nam Nakamori				1				
Task oriented weighting in multi-criteria analysis	1999	Yeh, C. H. Willis, R. J. Deng, H. P. Pan, H. Q.		1	1					
A combined approach for equipment selection: F-PROMETHEE method and zero-	2011	Yilmaz, Burcu Dagdevi	1	1	1					

one goal programming		ren, Metin								
A fuzzy ordering on multi-dimensional fuzzy sets induced from convex cones	2002	Yoshida, Y. Kerre, E. E.	1							
Rank B2C e-commerce websites in e-alliance based on AHP and fuzzy TOPSIS	2011	Yu, Xiaobing Guo, Shunsheng Guo	1		1	1				
A weighted additive fuzzy programming approach for multi-criteria supplier selection	2011	Yucel, Atakan Guneri, Ali Fuat		1			1			
Group decision making process for insurance company selection problem with extended VIKOR method under fuzzy environment	2012	Yucenur, G. Nilay Demirel, Nihan Cetin		1	1					
A fuzzy group multi-criteria enterprise architecture framework selection model	2012	Zandi, Faramak Tavana, Madjid		1	1					
Revising the OWA operator for multi criteria decision making problems under uncertainty	2009	Zarghami, Mahdi Szidarovszky, Ferenc	1			1				
On the relation between Compromise Programming and Ordered Weighted Averaging operator	2010	Zarghami, Mahdi Szidarovszky, Ferenc								
A combined methodology for supplier selection and performance evaluation	2011	Zeydan, Mithat Colpan, Cuneyt Cobanoglu, Cemal		1	1	1				
A linguistic intelligent user guide for method selection in multi-objective decision support systems	2009	Zhang, Guangquan Lu, Jie								
A GRA-based intuitionistic fuzzy multi-criteria group decision making method for personnel selection	2011	Zhang, Shi-fang Liu, San-yang	1	1					1	
Bivariate models of optimism and pessimism in multi-criteria decision-making based on intuitionistic fuzzy sets	2011	Chen, Ting-Yu							1	
Index evaluations and business strategies on communities of practice	2009	Chu, Mei-Tai Khosla, Rajiv								

Appendix C

Dataset of articles related to hybridization of AI and MCDM

Fuzzy Techniques (FTs)			Types of "MCDM"		Operation													Application																Types of collaboration fuzzy techniques and "MCDM" methods				Types of "MCDM" Methods	
Article	Times cited	Year, 20...	MODM	MADM	Prediction	Ranking	Scheduling	Selection	Evaluation	Optimization	Assessment	Allocating	Comparison	Planning	Designing	Classification	Modelling	Concept Selection	Supplier Selection	Manufacturing	Industries	Risk Mgt.	Economy	Military	Environmental Mgt.	Project/service Mgt.	Information Mgt.	Medical	Location Selection	Human Resource Mgt.	Transportation	Energy Mgt.	Construction	T1	T2	T3	T4	Non Outranking	Outranking
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Evolutionary Algorithms			Types of "MCDM"		Operation													Application																Types of collaboration Evolutionary Algorithms and "MCDM" methods				Types of "MCDM" Methods	
Article	Times cited	Year 20	MODM	MADM	Prediction	Ranking	Scheduling	Selection	Evaluation	Optimization	Assessment	Allocating	Comparison	Planning	Designing	Classification	Modeling	Concept Selection	Supplier Selection	Manufacturing	Industries	Risk Mgt.	Economy	Military	Environmental Mgt.	Project/service Mgt.	Information Mgt.	Medical	Location Selection	Human Resource Mgt.	Transportation	Energy Mgt.	Construction	T1	T2	T3	T4	Non Outranking	Outranking
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[141]	24	03	1							1																								1					
[142]	0	12	1				1			1																								1					
[143]	12	08	1				1			1																									1			1	
[144]	0	12	1																	1														1					
[145]	15	09	1							1											1													1					
[146]	0	12	1							1																						1		1					
[147]	4	10	1							1					1																	1			1			1	
[148]	7	10	1							1					1																	1			1			1	
[149]	0	12	1							1																		1						1					
[150]	2	11	1							1																											1		
[151]	2	12	1							1																									1			1	

[152]	11	03	1								1				1										1									1					
[153]	1	06	1							1																								1					
[154]	25	09	1							1																											1		
[155]	0	11	1							1				1								1													1			1	
[156]	0	12	1							1															1										1			1	
[157]	9	11	1							1										1														1					
[158]	7	04	1				1		1	1																								1					
[159]	2	10	1							1					1																			1					
[160]	4	05	1					1		1					1																			1					
[161]	2	09	1							1					1						1													1					
[162]	7	07	1										1							1														1					
[163]	0	12	1					1																		1										1		1	

Artificial Neural Networks	Types of "MCDM"	Operation	Application	Types of collaboration ANNs and "MCDM" methods	Types of "MCDM" Methods

Article	Times cited	Year, 20…	MODM	MADM	Prediction	Ranking	Scheduling	Selection	Evaluation	Optimization	Assessment	Allocating	Comparison	Planning	Designing	Classification	Modeling	Concept Selection	Supplier Selection	Manufacturing	Industries	Risk Mgt.	Economy	Military	Environmental Mgt.	Project/service Mgt.	Information Mgt.	Medical	Location Selection	Human Resource Mgt.	Transportation	Energy Mgt.	Construction	T1	T2	T3	T4	Non Outranking	Outranking
[164]	4	08		1					1						1					1															1			1	
[165]	2	07	1							1					1			1																1					
[166]	11	07	1					1												1														1					
[167]	4	10	1							1																								1					
[168]	0	09	1												1		1																	1					
[169]	41	03	1														1			1														1					
[170]	2	11	1						1						1								1											1					
[171]	3	10	1		1			1																												1			1
[172]	5	09	1							1																								1					
[173]	15	10		1				1											1																	1		1	
[174]	2	11	1													1																	1	1					
[175]	0	11	1							1					1		1																		1			1	
[176]	5	02	1							1																								1					

Case Base Reasoning			Types of "MCDM"		Operation													Application																Types of collaborationof CBR and "MCDM" methods				Types of "MCDM" Methods	
Article	**Times cited**	**Year, 20…**	**MODM**	**MADM**	**Prediction**	**Ranking**	**Scheduling**	**Selection**	**Evaluation**	**Optimization**	**Assessment**	**Allocating**	**Comparison**	**Planning**	**Designing**	**Classification**	**Modeling**	**Concept Selection**	**Supplier Selectio**	**Manufacturing**	**Industries**	**Risk Mgt.**	**Economy**	**Military**	**Environmental Mgt**	**Project/service M**	**Information Mgt.**	**Medical**	**Location Selectio**	**Human Resource Mg**	**Transportation**	**Energy Mgt.**	**Construction**	**T1**	**T2**	**T3**	**T4**	**Non Outranking**	**Outranking**
[177]	2	09	1		1																													1					
[178]	32	02	1		1	1			1																										1				1
[179]	36	04	1		1	1			1																										1				1
[180]	4	11	1		1	1			1																										1				1
[181]	5	07		1					1							1									1										1			1	
[182]	1	12	1							1							1																	1					
[183]	3	10	1							1																								1					
[184]	3	12	1					1												1															1			1	
[185]	5	11	1							1	1					1	1								1									1					
[186]	21	06	1																	1															1				1

																			n						.	g t .			n	t .									
[187]	3	12		1		1		1	1																	1							1			1		1	
[188]	5	11		1										1																						1		1	
[189]	3	05	1					1																							1			1					
[190]	0	10	1							1	1																							1					
[191]	0	06		1					1								1																	1					
[192]	5	11	1		1					1																							1	1					
[193]	4	12		1																																1		1	
[194]	3	09		1				1												1																1		1	
[195]	3	05		1				1	1	1			1																					1					
[196]	9	11		1					1		1														1										1			1	
[197]	15	11		1				1																									1		1			1	

Expert Systems			Types of "MCDM"		Operation													Application																Types of collaboration of ESs and "MCDM" methods				Types of "MCDM" Methods	
Article	**Times cited**	**Year, 20…**	**MODM**	**MADM**	**Prediction**	**Ranking**	**Scheduling**	**Selection**	**Evaluation**	**Optimization**	**Assessment**	**Allocating**	**Comparison**	**Planning**	**Designing**	**Classification**	**Modeling**	**Concept Selection**	**Supplier Selection**	**Manufacturing**	**Industries**	**Risk Mgt.**	**Economy**	**Military**	**Environmental Mgt.**	**Project/service Mgt.**	**Information Mgt.**	**Medical**	**Location Selection**	**Human Resource Mgt.**	**Transportation**	**Energy Mgt.**	**Construction**	**T1**	**T2**	**T3**	**T4**	**Non Outranking**	**Outranking**
[198]	7	06	1					1												1																1		1	
[199]	3	07	1							1					1																		1	1					

[200]	1	11		1																						1								1					
[201]	10	06	1																							1									1			1	
[202]	7	10		1											1																			1					
[203]	9	09		1																			1										1		1			1	
[204]	3	10		1					1							1																	1		1			1	
[205]	9	10	1						1	1				1											1											1		1	
[206]	8	05	1						1	1																				1					1			1	

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Appendix D

Correlations of methods, operations and applications in IMCDM

a) Correlations of MCDM methods and SES operations

```
CORRELATIONS
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 /MISSING=PAIRWISE.
```

Notes

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	Cases Used	Statistics for each pair of variables are based on all the cases with valid data for that pair.

Syntax		CORRELATIONS /VARIABLES=ELECTRE PROMETHEE ANP AHP VIKOR DEMATEL TOPSIS SESpapers /PRINT=TWOTAIL NOSIG /MISSING=PAIRWISE.
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	Elapsed Time	00:00:01.15

[DataSet2]

Correlations

		ELECTRE	PROMETHEE	ANP	AHP	VIKOR
ELECTRE	Pearson Correlation	1	-.091	-.091	.107	.[a]
	Sig. (2-tailed)		.779	.779	.742	.
	N	12	12	12	12	12
PROMETHEE	Pearson Correlation	-.091	1	-.091	.426	.[a]
	Sig. (2-tailed)	.779		.779	.167	.
	N	12	12	12	12	12
ANP	Pearson Correlation	-.091	-.091	1	-.213	.[a]
	Sig. (2-tailed)	.779	.779		.506	.

	N	12	12	12	12	12
AHP	Pearson Correlation	.107	.426	-.213	1	.[a]
	Sig. (2-tailed)	.742	.167	.506		.
	N	12	12	12	12	12
VIKOR	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.	.	
	N	12	12	12	12	12
DEMATEL	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.	.	.
	N	12	12	12	12	12
TOPSIS	Pearson Correlation	-.127	.380	-.127	.891**	.[a]
	Sig. (2-tailed)	.695	.223	.695	.000	.
	N	12	12	12	12	12
SESpapers	Pearson Correlation	.062	.311	.062	.925**	.[a]
	Sig. (2-tailed)	.848	.325	.848	.000	.
	N	12	12	12	12	12

Correlations

		DEMATEL	TOPSIS	SESpapers
ELECTRE	Pearson Correlation	.[a]	-.127	.062
	Sig. (2-tailed)	.	.695	.848

	N	12	12	12
PROMETHEE	Pearson Correlation	.[a]	.380	.311
	Sig. (2-tailed)	.	.223	.325
	N	12	12	12
ANP considered	Pearson Correlation	.[a]	-.127	.062
	Sig. (2-tailed)	.	.695	.848
	N	12	12	12
AHP	Pearson Correlation	.[a]	.891**	.925**
	Sig. (2-tailed)	.	.000	.000
	N	12	12	12
VIKOR	Pearson Correlation	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.
	N	12	12	12
DEMATEL	Pearson Correlation	.[a]	.[a]	.[a]
	Sig. (2-tailed)		.	.
	N	12	12	12
TOPSIS	Pearson Correlation	.[a]	1	.819**
	Sig. (2-tailed)	.		.001
	N	12	12	12
SESpapers	Pearson Correlation	.[a]	.819**	1
	Sig. (2-tailed)	.	.001	
	N	12	12	12

**. Correlation is significant at the 0.01 level (2-tailed).

GRAPH

/SCATTERPLOT(OVERLAY)=SESpapers SESpapers SESpapers SESpapers SESpapers SESpapers SESpapers WITH ELECTRE PROMETHEE ANP AHP VIKOR DEMATEL TOPSIS (PAIR)

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Graph

Notes

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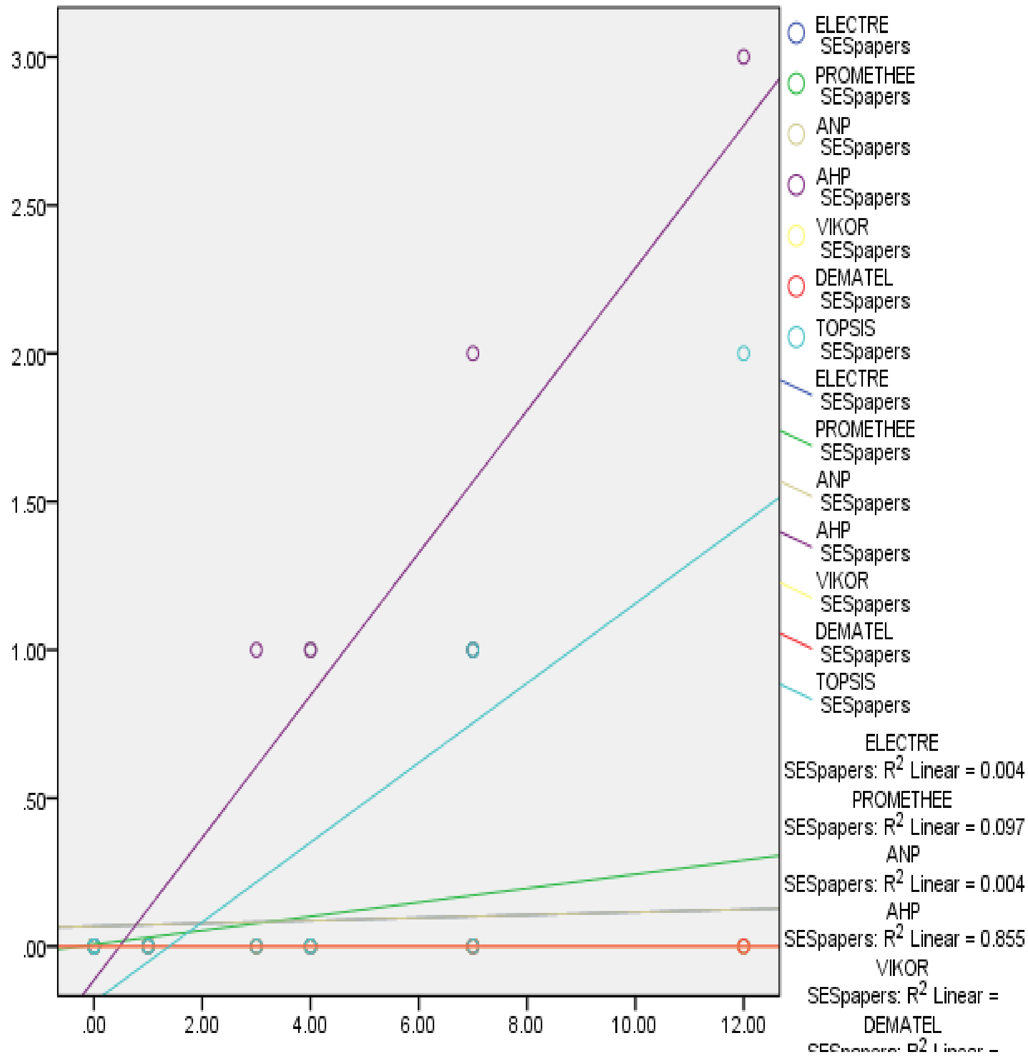

b) Correlations of Fuzzy techniques and SES operations

```
CORRELATIONS
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```

Notes

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	Cases Used	Statistics for each pair of variables are based on all the cases with valid data for that pair.
Syntax		CORRELATIONS /VARIABLES=FT ERS.FT /PRINT=TWOTAIL NOSIG /MISSING=PAIRWISE.
Resources	Processor Time	00:00:00.02

Elapsed Time	00:00:00.06

Correlations

		FT	ERS.FT
FT	Pearson Correlation	1	.976**
	Sig. (2-tailed)		.000
	N	12	12
ERS.FT	Pearson Correlation	.976**	1
	Sig. (2-tailed)	.000	
	N	12	12

**. Correlation is significant at the 0.01 level (2-tailed).

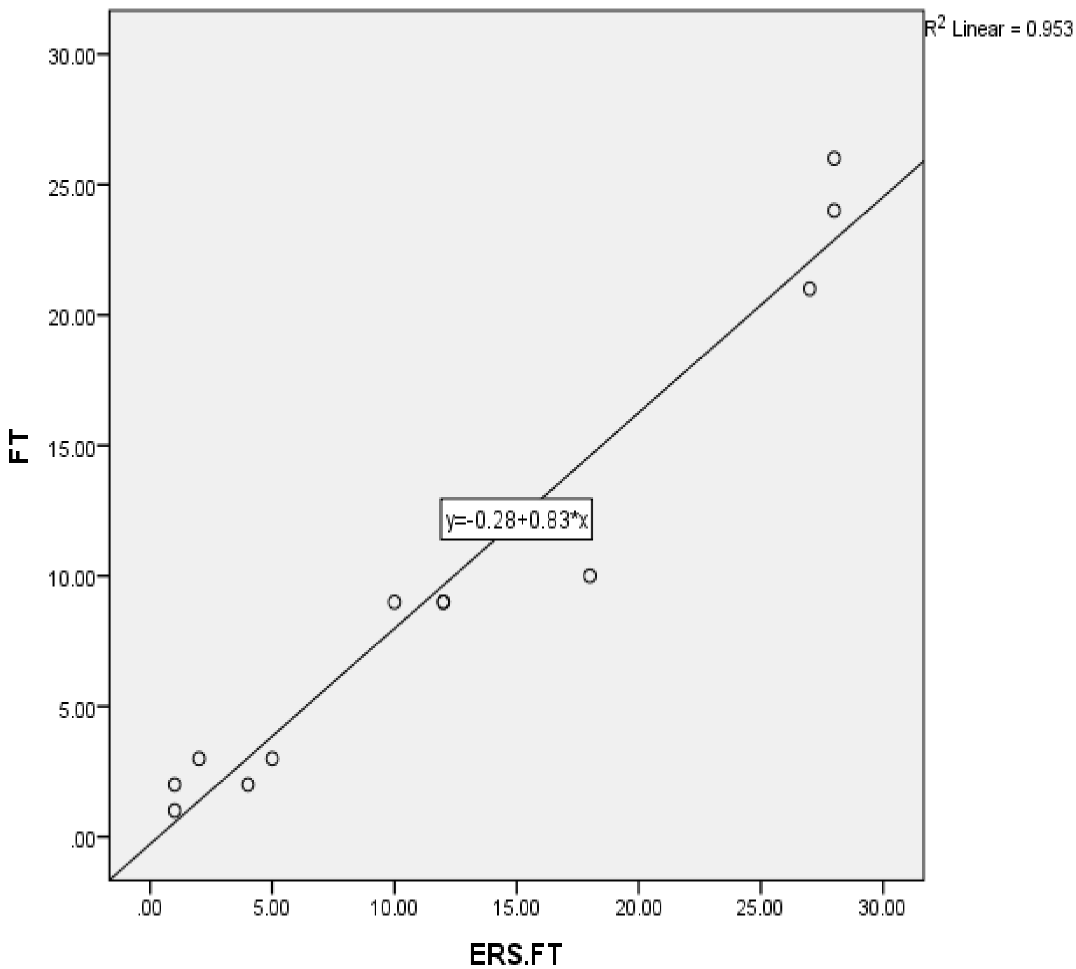
```
GRAPH
 /SCATTERPLOT(BIVAR)=ERS.FT WITH FT
 /MISSING=LISTWISE.
```

Graph

Notes

Output Created		24-JAN-2014 14:25:36
Comments		
Input	Active Dataset	DataSet0
	Filter	<none>
	Weight	<none>
	Split File	<none>

	N of Rows in Working Data File	12
Syntax		GRAPH /SCATTERPLOT(BIVAR)=ERS.FT WITH FT /MISSING=LISTWISE.
Resources	Processor Time	00:00:00.22
	Elapsed Time	00:00:00.36



c) Correlations of Expert systems and SES operations

```
CORRELATIONS
  /VARIABLES=ES ERS.ES
  /PRINT=TWOTAIL NOSIG
  /MISSING=PAIRWISE.
```

Notes

Output Created		27-JAN-2014 14:29:18
Comments		
Input	Data	C:\Users\Adalleh\Desktop\scientometric\for statistic process\spss.ERS.sav
	Active Dataset	DataSet1
	N of Rows in Working Data File	12
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics for each pair of variables are based on all the cases with valid data for that pair.
Syntax		CORRELATIONS /VARIABLES=ES ERS.ES /PRINT=TWOTAIL NOSIG /MISSING=PAIRWISE.
Resources	Processor Time	00:00:00.03
	Elapsed Time	00:00:00.09

Correlations

		ES	ERS.ES
ES	Pearson Correlation	1	.922**
	Sig. (2-tailed)		.000
	N	12	12
ERS.ES	Pearson Correlation	.922**	1
	Sig. (2-tailed)	.000	
	N	12	12

**. Correlation is significant at the 0.01 level (2-tailed).

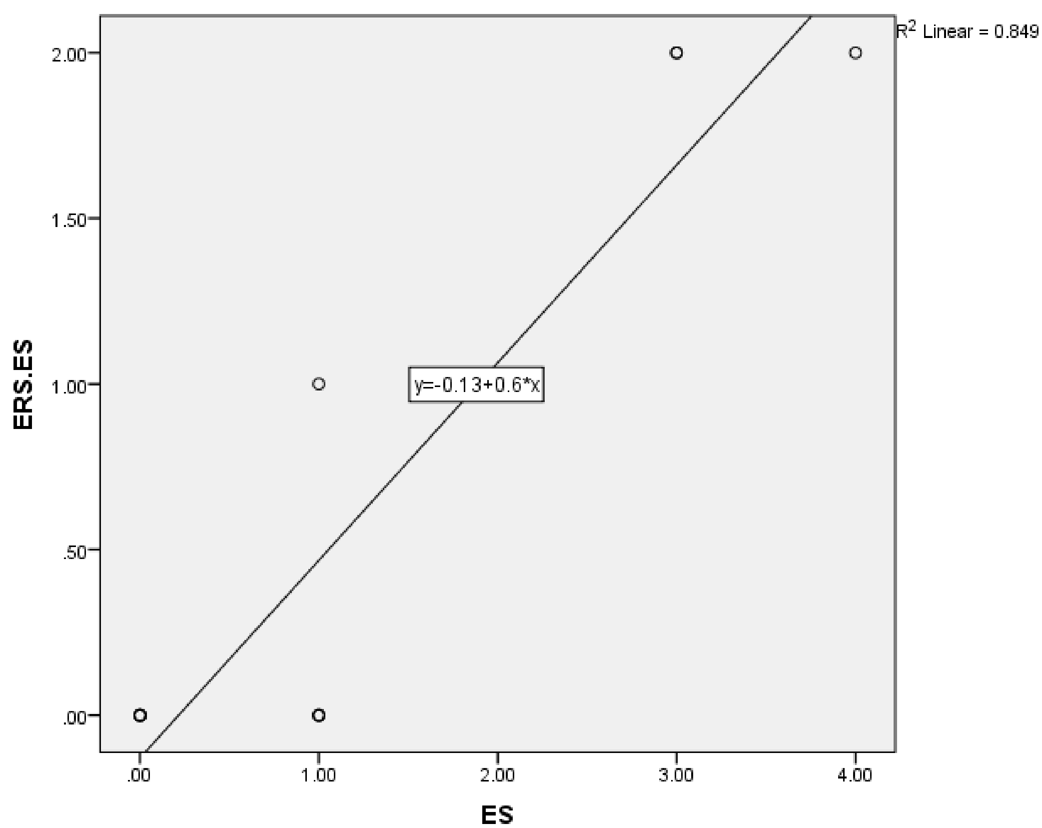
```
GRAPH
 /SCATTERPLOT(BIVAR)=ES WITH ERS.ES
 /MISSING=LISTWISE.
```

Graph

Notes

Output Created		27-JAN-2014 14:29:48
Comments		
Input	Data	C:\Users\Adalleh\Desktop\scientometric\for statistic process\spss.ERS.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>

	Split File	<none>
	N of Rows in Working Data File	12
Syntax		GRAPH /SCATTERPLOT(BIVAR)=ES WITH ERS.ES /MISSING=LISTWISE.
Resources	Processor Time	00:00:00.22
	Elapsed Time	00:00:00.23



d) Correlations of Evolutionary Algorithm and SES operations

CORRELATIONS

/VARIABLES=EA ERS.EA

/PRINT=TWOTAIL NOSIG

/MISSING=PAIRWISE.

Notes

Output Created		24-JAN-2014 14:19:10
Comments		
Input	Active Dataset	DataSet0
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	12
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics for each pair of variables are based on all the cases with valid data for that pair.
Syntax		CORRELATIONS /VARIABLES=EA ERS.EA /PRINT=TWOTAIL NOSIG /MISSING=PAIRWISE.
Resources	Processor Time	00:00:00.00
	Elapsed Time	00:00:00.01

Correlations

		EA	ERS.EA
EA	Pearson Correlation	1	.678*
	Sig. (2-tailed)		.015
	N	12	12
ERS.EA	Pearson Correlation	.678*	1
	Sig. (2-tailed)	.015	
	N	12	12

*. Correlation is significant at the 0.05 level (2-tailed).

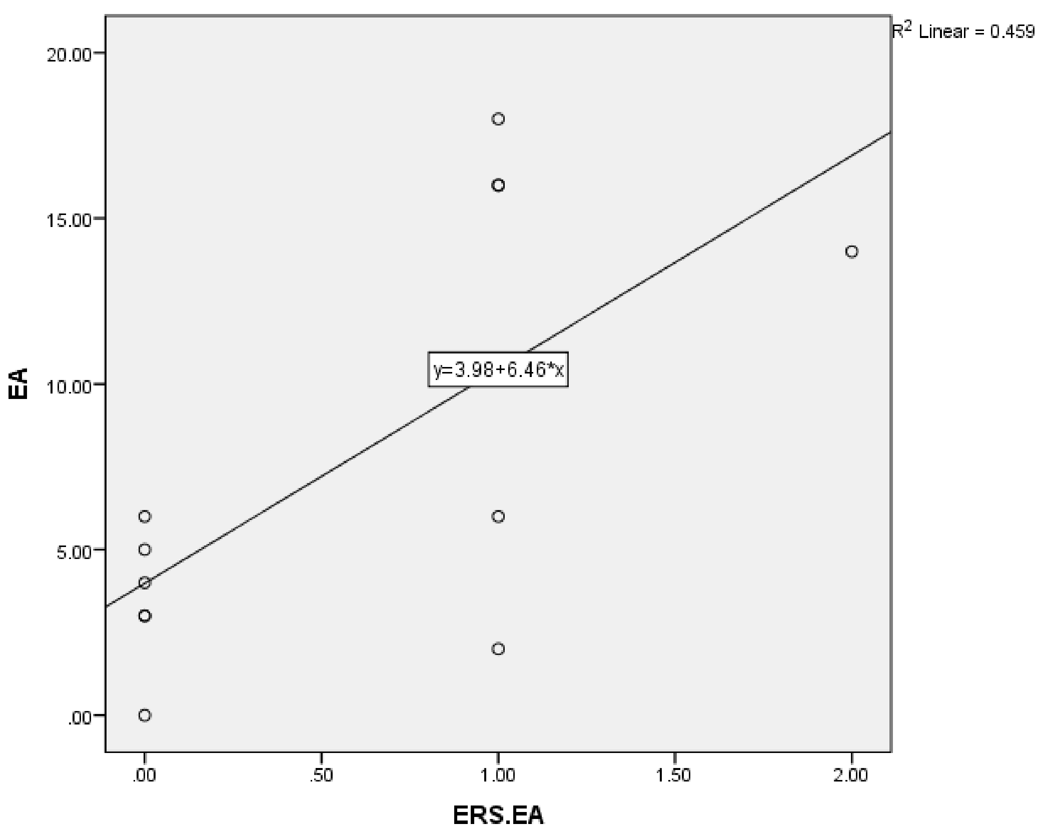
```
GRAPH
 /SCATTERPLOT(BIVAR)=ERS.EA WITH EA
 /MISSING=LISTWISE.
```

Graph

Notes

Output Created		24-JAN-2014 14:20:21
Comments		
Input	Active Dataset	DataSet0
	Filter	<none>
	Weight	<none>
	Split File	<none>

	N of Rows in Working Data File	12
Syntax		GRAPH /SCATTERPLOT(BIVAR)=ERS.EA WITH EA /MISSING=LISTWISE.
Resources	Processor Time	00:00:00.36
	Elapsed Time	00:00:08.36



e) Correlations of CBR and SES operations

CORRELATIONS

/VARIABLES=CBR ERS.CBR

/PRINT=TWOTAIL NOSIG

/MISSING=PAIRWISE.

Notes

Output Created		27-JAN-2014 14:32:21
Comments		
Input	Data	C:\Users\Adalleh\Desktop\scientometric\for statistic process\spss.ERS.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	12
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics for each pair of variables are based on all the cases with valid data for that pair.
Syntax		CORRELATIONS /VARIABLES=CBR ERS.CBR /PRINT=TWOTAIL NOSIG /MISSING=PAIRWISE.
Resources	Processor Time	00:00:00.03

Elapsed Time	00:00:00.10

Correlations

		CBR	ERS.CBR
CBR	Pearson Correlation	1	.790**
	Sig. (2-tailed)		.002
	N	12	12
ERS.CBR	Pearson Correlation	.790**	1
	Sig. (2-tailed)	.002	
	N	12	12

**. Correlation is significant at the 0.01 level (2-tailed).

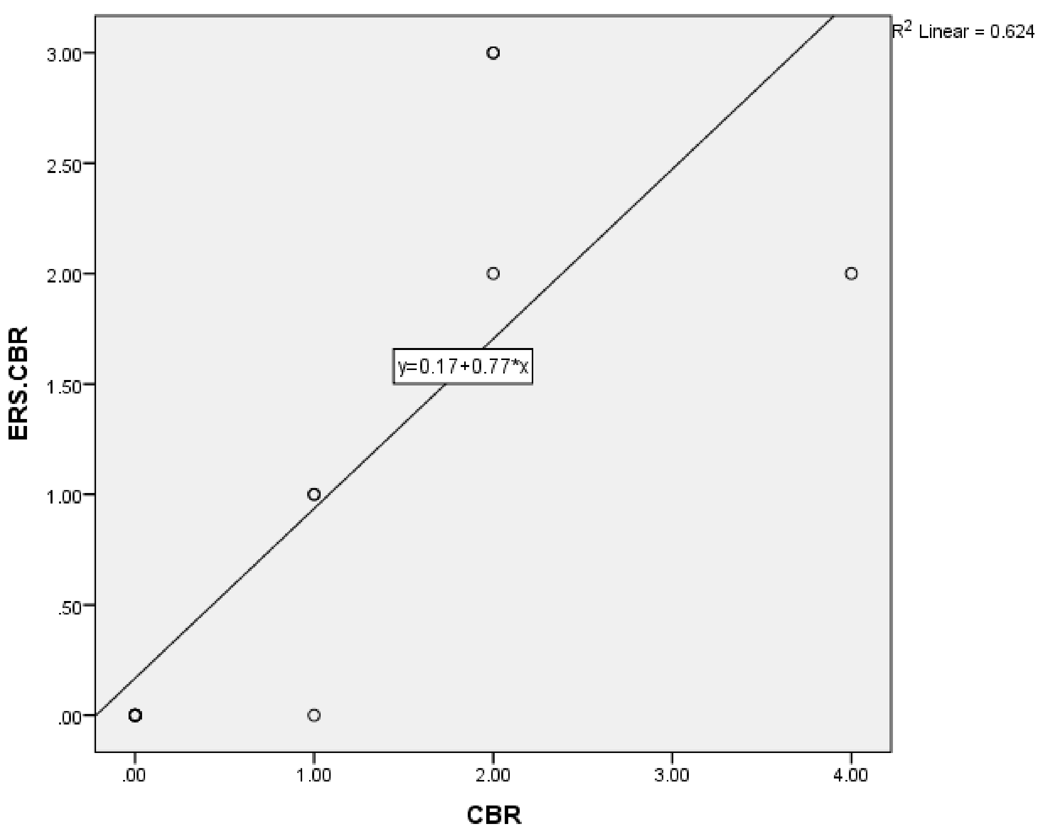
```
GRAPH
 /SCATTERPLOT(BIVAR)=CBR WITH ERS.CBR
 /MISSING=LISTWISE.
```

Graph

Notes

Output Created		27-JAN-2014 14:32:48
Comments		
Input	Data	C:\Users\Adalleh\Desktop\scientometric\for statistic process\spss.ERS.sav

	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	12
Syntax		GRAPH /SCATTERPLOT(BIVAR)=CBR WITH ERS.CBR /MISSING=LISTWISE.
Resources	Processor Time	00:00:00.22
	Elapsed Time	00:00:00.26



f) Correlations of ANN and SES operations

```
CORRELATIONS

 /VARIABLES=ANN ERS.ANN

 /PRINT=TWOTAIL NOSIG

 /MISSING=PAIRWISE.
```

Notes

Output Created		27-JAN-2014 14:24:25
Comments		
Input	Data	C:\Users\Adalleh\Desktop\scientometric\for statistic process\spss.ERS.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	12
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics for each pair of variables are based on all the cases with valid data for that pair.
Syntax		CORRELATIONS /VARIABLES=ANN ERS.ANN /PRINT=TWOTAIL NOSIG /MISSING=PAIRWISE.

Resources	Processor Time	00:00:00.05
	Elapsed Time	00:00:00.48

[DataSet1] C:\Users\Adalleh\Desktop\scientometric\for statistic process\spss.ERS.sav

Correlations

		ANN	ERS.ANN
ANN	Pearson Correlation	1	.570
	Sig. (2-tailed)		.053
	N	12	12
ERS.ANN	Pearson Correlation	.570	1
	Sig. (2-tailed)	.053	
	N	12	12

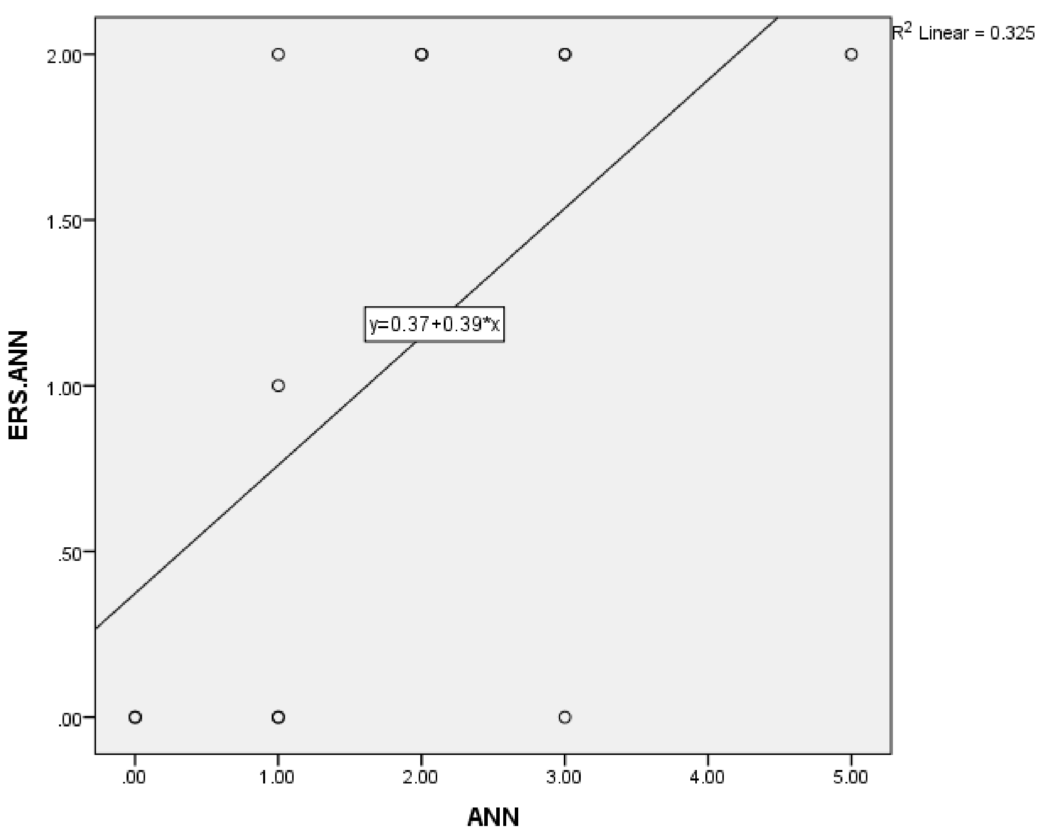
```
GRAPH
 /SCATTERPLOT(BIVAR)=ANN WITH ERS.ANN
 /MISSING=LISTWISE.
```

Graph

Notes

Output Created	27-JAN-2014 14:25:43
Comments	

Input	Data	C:\Users\Adalleh\Desktop\scientometric\for statistic process\spss.ERS.sav
	Active Dataset	DataSet1
	N of Rows in Working Data File	12
Syntax		GRAPH /SCATTERPLOT(BIVAR)=ANN WITH ERS.ANN /MISSING=LISTWISE.
Resources	Processor Time	00:00:00.87
	Elapsed Time	00:00:06.83



Appendix E

Decision makers' questionnaire

This form is part of a thesis by Adeleh Asemi, Ph.D. student from the Department of Artificial Intelligence, Faculty of Computer Science and Information Technology, University of Malaya. The purpose of this questionnaire is to evaluate the suppliers of ball-bearing in Mobarake steel company.

Your relevant experience and expertise is greatly valued and you are invited to participate in this survey.

Your honesty and sincerity are highly required in attempting this questionnaire. Please give a response that you think is most appropriate to each question.

Not. The questioner supposed to be completed in two sessions. In a first session, please complete the A and B part and in second session you will receive the C and D part.

Questions about this study should be directed to Adeleh Asemi, Investigator, at: asemi@siswa.um.edu.my. Your contribution towards this survey is highly appreciated.

Adeleh Asemi

General Information

1. Name of company:

2. Your position in company:

3. How your idea is important in this decision making:

a. Absolute [ ]   b. Very important [ ]   c. Important [ ]

d. Fairly important [ ]   e. Not important [ ]

Part A, determination of criteria

Note: Please look at the list of criteria provided in the bellow, then for each criterion, determine that whether you consider it for your decision or no? Even if the consideration is very low, please answer yes.

Product

C1 (Ease of operation[1]):	Yes [ ]	No [ ]
C2 (Impact on energy utilization):	Yes [ ]	No [ ]
C3 (Ease of maintenance design):	Yes [ ]	No [ ]
C4 (Amount of pre-purchase information):	Yes [ ]	No [ ]
C5 (Contribution to productivity):	Yes [ ]	No [ ]
C6 (Cost of service contract):	Yes [ ]	No [ ]

Availability

C7 (Breadth of product line):	Yes [ ]	No [ ]
C8 (Geographic proximity):	Yes [ ]	No [ ]
C9 (Vendor's image):	Yes [ ]	No [ ]
C10 (Financial capacity):	Yes [ ]	No [ ]
C11 (Quality Assurance):	Yes [ ]	No [ ]

[1] Swift, C. O. (1995). Preferences for single sourcing and supplier selection criteria. *Journal of Business Research*, *32*(2), 105-111.

Dependability

C12 (On time delivery):	Yes	[ ]	No	[ ]
C13 (Technical abilities):	Yes	[ ]	No	[ ]
C14 (Reliability of product):	Yes	[ ]	No	[ ]
C15 (Service response time):	Yes	[ ]	No	[ ]

Experience

C16 (Preferences established by users):	Yes	[ ]	No	[ ]
C17 (Prior experience with vendors):	Yes	[ ]	No	[ ]
C18 (Reputation of suppliers):	Yes	[ ]	No	[ ]

Price

C19 (Price/performance):	Yes	[ ]	No	[ ]
C20 (Low price):	Yes	[ ]	No	[ ]
C21 (Total cost of product):	Yes	[ ]	No	[ ]

C22. Others [ ]

Part B, environment

The following elements have defined for the environment of decision making:

Re-ranking: The alternatives are not fixed and even after ranking may need to enter new alternative and repeat evaluation and ranking of them.

Inconsistency: The opinion of decision makers is different or because of any reason they don't fill the questioners properly.

Homogeny: Each supplier is not good only in special criteria (The suppliers are not specialist).

A-Population: The number of suppliers.

Please determine the probability of each element by putting the cross mark "X" in the place that you prefer. Or, tick the box which you prefer.

Re-ranking:

0 10 20 30 40 50 60 70 80 90 100

a. Very high [ ] b. High [] c. Medium [ ]

d. Low [ ] e. Very low [ ]

Inconsistency:

0 10 20 30 40 50 60 70 80 90 100

a. Very high [ ] b. High [] c. Medium [ ]

d. Low [ ] e. Very low [ ]

Homogeny:

0 10 20 30 40 50 60 70 80 90 100

a. Very high [ ] b. High [] c. Medium [ ]

d. Low [ ] e. Very low [ ]

A-Population

How many suppliers are willing to supply ball-bring? Please list their names and codes.

Part C, comparison of criteria

Based on your idea and other experts' opinion in the previous session, the following table is designed to compare the effective criteria for ball-bearing supplier selection.
Note:
If criterion on the left is more important than the one on the right, put a cross mark "X" to one of the cells, based on the importance level (column) that you prefer.

Criteria	Perfect	Absolute	Very good	Fairly good	Good	Preferable	Not bad	Weak advantage	Equal	**Criteria**
Financial capacity										Quality Assurance
Financial capacity										On time delivery
Financial capacity										Technical abilities
Quality Assurance										On time delivery
Quality Assurance										Technical abilities
On time delivery										Technical abilities

Criteria	Perfect	Absolute	Very good	Fairly good	Good	Preferable	Not bad	Weak advantage	Equal	**Criteria**
Quality Assurance										Financial capacity
On time delivery										Financial capacity
Technical abilities										Financial capacity

On time delivery										Quality Assurance
Technical abilities										Quality Assurance
Technical abilities										On time delivery

Part D, comparison of alternatives

This part is related to comparison of suppliers in each criterion.

Please use the corresponding number to show the ability degree of alternatives in each criterion.

	Perfect	Absolute	Very good	Fairly good	Good	Preferable	Not bad	Weak advantage	Weak (Equal)
Correspond number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**

No.	Name of Suppliers	Financial capacity	Quality Assurance	On time delivery	Technical abilities
1	Kahroba				
2	Barghara				
3	Rahbaran Foolad				
4	Alitajhiz				
5	Veghar Kavir				
6	Tadavom Sanaye				
7	Tara				
8	Mattex				

Appendix F

Correlation of models' results and experts' judgment

a) Experiment 1

```
CORRELATIONS
  /VARIABLES=FDHM FHM FFAHP Experts
  /PRINT=TWOTAIL NOSIG
  /MISSING=PAIRWISE.
```

Correlations

Notes

Output Created		22-FEB-2014 14:50:38
Comments		
Input	Data	C:\Users\Adalleh\Desktop\FHM\fhm.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	20
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics for each pair of variables are based on all the cases with valid data for that pair.
Syntax		CORRELATIONS /VARIABLES=FDHM FHM FFAHP Experts /PRINT=TWOTAIL NOSIG /MISSING=PAIRWISE.
Resources	Processor Time	00:00:00.00
	Elapsed Time	00:00:00.03

Correlations

		FDHM	FHM	FFAHP	Experts
FDHM	Pearson Correlation	1	1.000**	.224	.892**
	Sig. (2-tailed)		.000	.342	.000
	N	20	20	20	20
FHM	Pearson Correlation	1.000**	1	.224	.892**
	Sig. (2-tailed)	.000		.342	.000
	N	20	20	20	20
FFAHP	Pearson Correlation	.224	.224	1	.265
	Sig. (2-tailed)	.342	.342		.259
	N	20	20	20	20
Experts	Pearson Correlation	.892**	.892**	.265	1
	Sig. (2-tailed)	.000	.000	.259	
	N	20	20	20	20

**. Correlation is significant at the 0.01 level (2-tailed).

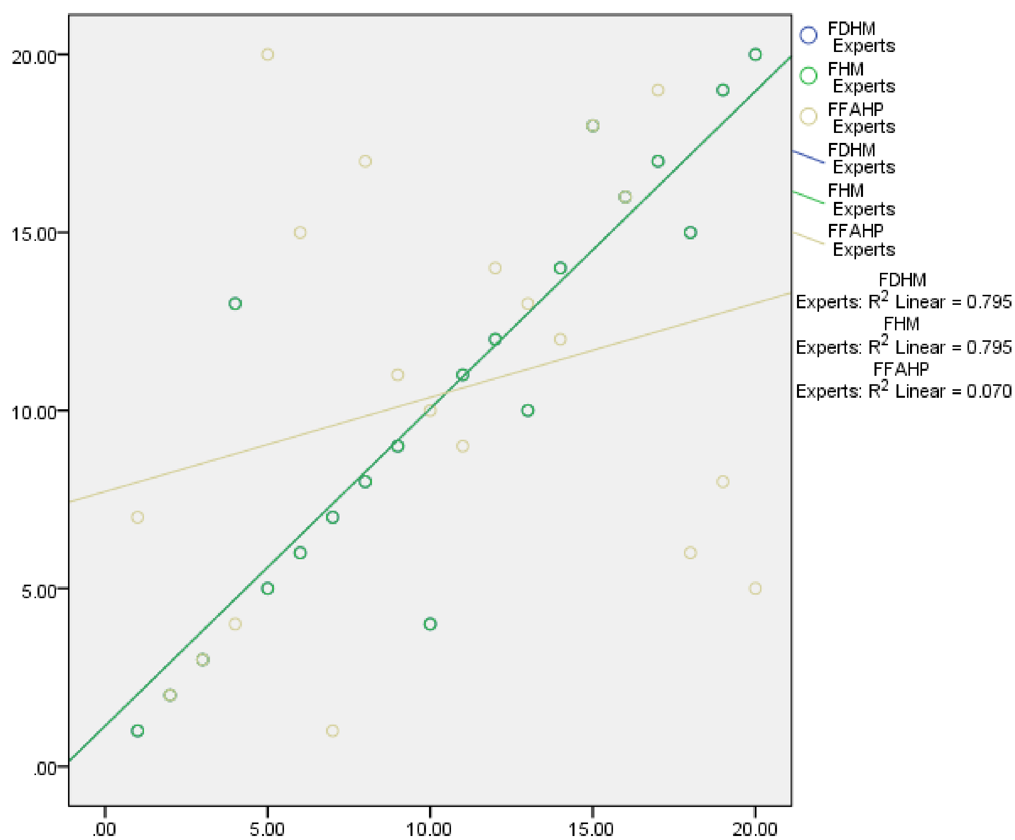
```
GRAPH
  /SCATTERPLOT(OVERLAY)=Experts Experts Experts WITH FDHM FHM FFAHP
(PAIR)
  /MISSING=LISTWISE.
```

Graph

Notes

Output Created		22-FEB-2014 14:50:52
Comments		
Input	Data	C:\Users\Adalleh\Desktop\FHM\fhm.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>

	N of Rows in Working Data File	20
Syntax		GRAPH /SCATTERPLOT(OVERLAY)=Experts Experts Experts WITH FDHM FHM FFAHP (PAIR) /MISSING=LISTWISE.
Resources	Processor Time	00:00:00.22
	Elapsed Time	00:00:00.31



b) Experiment 2

```
CORRELATIONS
  /VARIABLES=FDHM FHM FFAHP Experts
  /PRINT=TWOTAIL NOSIG
  /MISSING=PAIRWISE.
```

Correlations

Notes

Output Created		22-FEB-2014 14:37:46
Comments		
Input	Data	C:\Users\Adalleh\Desktop\FFAHP\ffahp.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	20
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics for each pair of variables are based on all the cases with valid data for that pair.
Syntax		CORRELATIONS /VARIABLES=FDHM FHM FFAHP Experts /PRINT=TWOTAIL NOSIG /MISSING=PAIRWISE.
Resources	Processor Time	00:00:00.11
	Elapsed Time	00:00:00.12

Correlations

		FDHM	FHM	FFAHP	Experts
FDHM	Pearson Correlation	1	.436	1.000**	.998**
	Sig. (2-tailed)		.055	.000	.000
	N	20	20	20	20
FHM	Pearson Correlation	.436	1	.436	.456*
	Sig. (2-tailed)	.055		.055	.043
	N	20	20	20	20
FFAHP	Pearson Correlation	1.000**	.436	1	.998**
	Sig. (2-tailed)	.000	.055		.000
	N	20	20	20	20
Experts	Pearson Correlation	.998**	.456*	.998**	1
	Sig. (2-tailed)	.000	.043	.000	
	N	20	20	20	20

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

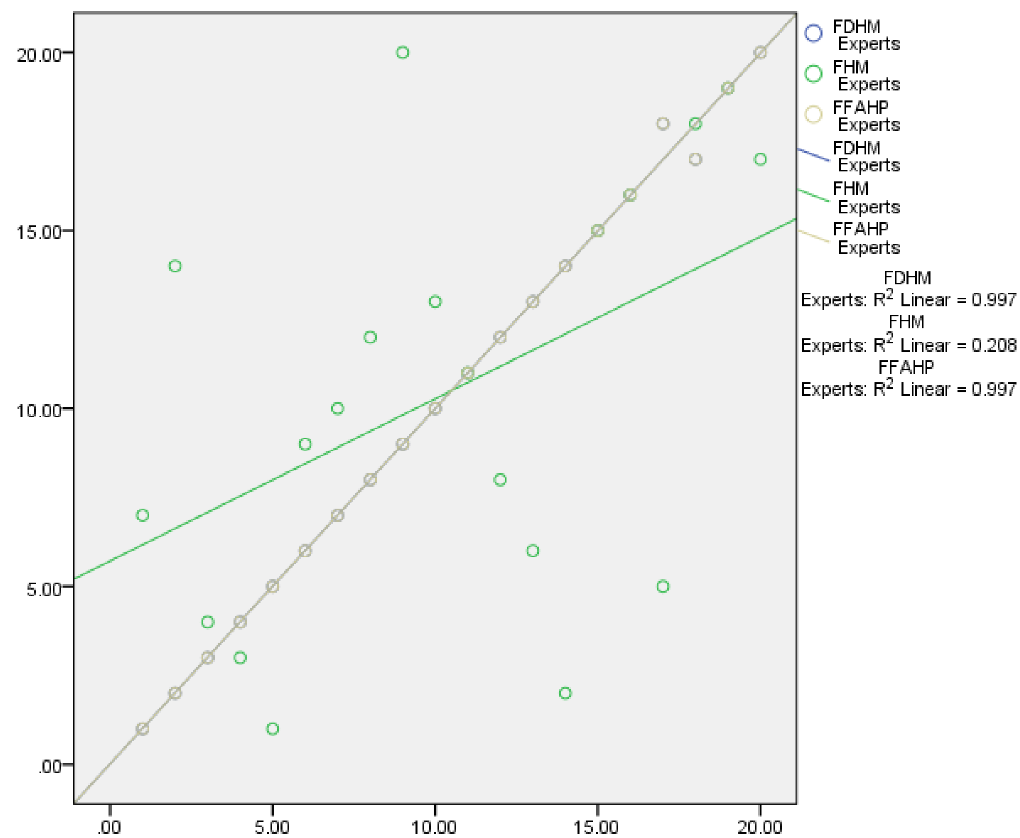
```
GRAPH
  /SCATTERPLOT(OVERLAY)=Experts Experts Experts WITH FDHM FHM
FFAHP (PAIR)
  /MISSING=LISTWISE.
```

Graph

Notes

Output Created	22-FEB-2014 14:38:52

Comments		
Input	Data	C:\Users\Adalleh\Desktop\FFAHP\ffahp.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	20
Syntax		GRAPH /SCATTERPLOT(OVERLAY)=Experts Experts Experts WITH FDHM FHM FFAHP (PAIR) /MISSING=LISTWISE.
Resources	Processor Time	00:00:00.94
	Elapsed Time	00:00:01.31



c) Experiment 3

```
CORRELATIONS
  /VARIABLES=FDHM FHM FFAHP Experts
  /PRINT=TWOTAIL NOSIG
  /MISSING=PAIRWISE.
```

Notes

Output Created		19-FEB-2014 11:57:26
Comments		
Input	Data	C:\Users\Adalleh\Desktop\combination.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	10
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics for each pair of variables are based on all the cases with valid data for that pair.
Syntax		CORRELATIONS /VARIABLES=FDHM FHM FFAHP Experts /PRINT=TWOTAIL NOSIG /MISSING=PAIRWISE.
Resources	Processor Time	00:00:00.08
	Elapsed Time	00:00:00.08

Correlations

		FDHM	FHM	FFAHP	Experts
FDHM	Pearson Correlation	1	.467	.806**	.891**

	Sig. (2-tailed)		.174	.005	.001
	N	10	10	10	10
FHM	Pearson Correlation	.467	1	.224	.503
	Sig. (2-tailed)	.174		.533	.138
	N	10	10	10	10
FFAHP	Pearson Correlation	.806**	.224	1	.697*
	Sig. (2-tailed)	.005	.533		.025
	N	10	10	10	10
Experts	Pearson Correlation	.891**	.503	.697*	1
	Sig. (2-tailed)	.001	.138	.025	
	N	10	10	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

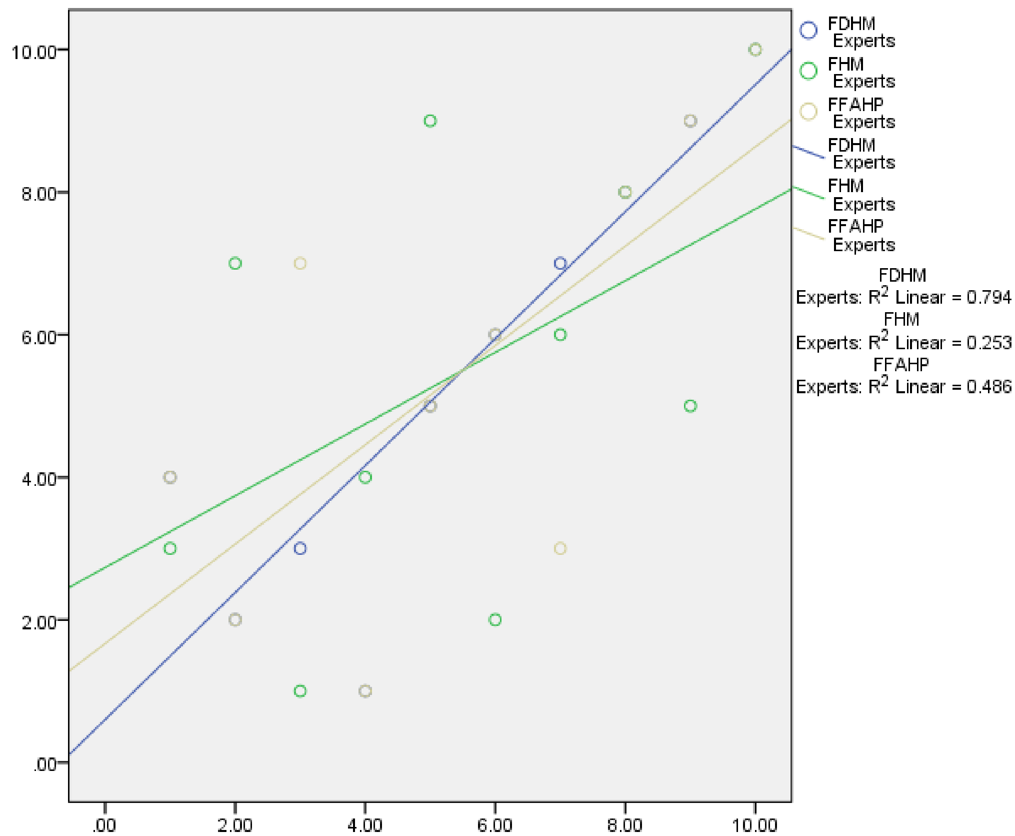
```
GRAPH
  /SCATTERPLOT(OVERLAY)=Experts Experts Experts WITH FDHM FHM
FFAHP (PAIR)
  /MISSING=LISTWISE.
```

Graph

Notes

Output Created		19-FEB-2014 11:57:58
Comments		
Input	Data	C:\Users\Adalleh\Desktop\combination.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>

	N of Rows in Working Data File	10
Syntax		GRAPH /SCATTERPLOT(OVERLAY)=Experts Experts Experts WITH FDHM FHM FFAHP (PAIR) /MISSING=LISTWISE.
Resources	Processor Time	00:00:00.23
	Elapsed Time	00:00:00.24



Appendix G

Research project proposal to Mobarake steel company

شرکت فولاد مبارکه

معاونت تکنولوژي
تحقيق و توسعه
Research & Development
شناسنامه طرح پژوهشي

عنوان طرح پژوهشي :
پياده سازی يک سيستم هوشمند پشتيبان تصميم جهت انتخاب تامين کنندگان

عنوان طرح به زبان انگليسي :

An intelligent decision support system to selection of suppliers

مسئول طرح پژوهشي:. دکترعاصمی

تاريخ تصويب طرح پژوهشي :

مدت اجراء طرح پژوهشي : 1 سال

اعتبار طرح :

1- **عنوان طرح پژوهشي :**
پیاده سازی یک سیستم هوشمند پشتیبان تصمیم جهت انتخاب تامین کنندگان

2- **مسئول طرح پژوهشي :** دکتر عاصفه عاصمی
سمت مسئول طرح پژوهشي : مدیر گروه و عضو هیات علمی دانشگاه اصفهان
محل کار مسئول طرح: دانشگاه اصفهان
آدرس و تلفن : دانشگاه اصفهان – تلفن: 7932125

3- **نام همکاران اصلي مسئول پژوهشي با ذکر سمت و محل کار :**
عادله عاصمی دانشجوی دکترای هوش مصنوعی دانشگاه مالایا
علی علی بیگی دانشجوی دکترا ی تجارت الکترونیک دانشگاه مالایا
محمد حسین هوشنگی – مهندس نرم افزار
مشاور طرح: آقای مهندس رسول غفاری (رییس برنامه ریزی و کنترل ساخت قطعات یدکی شرکت فولاد مبارکه)

4- طرحهاي ديگر پژوهش در دست اجراء مسئول طرح(با ذکر عنوان شرح ، ميزان اعتبار و تاريخ پايان طرح)
طرح پژوهشی سنجش و توسعه سواد اطلاعاتی متخصصبن شرکت فولاد مبارکه- میزان اعتبار چهار میلیون و پانصد هزارتومان و تاریخ اتمام پایان شهریور 90 می باشد.

5- خلاصه طرح پژوهشي (حداکثر در 100 کلمه نوشته شود)
در این طرح هدف پیاده سازی یک سیستم هوشمند تصمیم یار برای کمک به مدیر در تصمیم گیری برای ارزیابی و انتخاب تامین کننده ها می باشد. این سیستم در واقع دانش مدیر در زمینه تصمیم گیری شبیه سازی می کند ومانند یک متخصص استنتاج می کند.
این سیستم هوشمند شامل یک سیستم خبره فازی بهمراه تکنیک های مدیریت(تصمیم گیری های چند شاخصه فازی) می باشد. این سیستم خبره شامل یک پایگاه دانش ویک موتور جستجوست اگر یک سوال از سیستم خبره پرسیده شود سیستم تلاش خواهد کرد با استفاده از منطق واکتشافهای موتور جستجو ، جواب را از پایگاه دانش پیدا کند . به عنوان مثال سیستم در تعاملی که با مدیردارد از او مسئله یا مورد تصمیم را سوال می کند و شرایط و اطلاعات مورد نیاز دیگر در مورد این مسئله را نیز سوال می کند ، سپس با در نظر گرفتن داده های ورودی ونیز تکنیک ها و قوانینی که قبلا در پایگاه دانش قرار داده شده ، در پایگاه دانش جستجو می کند و تصمیم دقیق و درست را با استفاده از موتور استنتاج به عنوان خروجی باز می گرداند.

6- طرح پژوهشي در كداميك از زمينه هاي زير نقش دارد ؟ (فقط به توضيح مهمترين نقش بپرازيد)
1- افزايش كيفيت محصولات
2- ✓ كاهش هزينه هاي توليد و نهايتا كاهش قيمت تمام شده
3- ✓ افزايش راندمان توليد
4- افزايش دانش فني و ارتقاء تكنولوژي
5- ✓ بالا بردن ارزش افزوده
6- ✓ بهينه سازي سيستمهاي توليد و پشتيباني توليد
7- قطع واردات و كاهش وابستگي
8- ✓ كاهش ضايعات و استفاده مجدد از آنها
9- كاهش مصرف مواد و انرژي
10- افزايش كارآيي نيروي انساني شاغل در شركت
11- جوابگوئي به نياز بازار
12- استفاده بهتر از امكانات توليدي و پشتيباني توليد موجود
13- جايگزيني مواد اوليه مناسبتر
14- ايجاد سرمايه گذاري هاي بنيادي و ضروري در كشور
15- ✓ كاهش آلودگي محيط زيست
16- تكميل و يا انجام پروژه هاي تحقيقاتي ديگر
17- افزايش ايمني كار
18- تكميل حلقه هاي توليد

7- آيا در رابطه با طرح پژوهشي ارائه شده كارهائي در ايران و يا خارج از كشورانجام گرفته است؟ (با ذكر ماخذ) .
در ایران و خارج نمونه های زیادی از استفاده تکنیک MCDMبرای انتخاب تامین کننده در شرکت ها و بخش های مختلف صنعتی داریم که در زیر نمونه هایی ازکاربرد آن که در ژورنال های معتبر جهانی به چاپ رسیده است آورده شده تفاوت اصلی این سیستم با سیستم های موجود هوشمند بودن آن است که باعث می شود تصمیم گیری های بهینه میشودو به تصمیم گیریهای انسانی نزدیکتر گردد.

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حسن صراف جوشقانی . بررسی و مقایسه پژوهش های دانشجویی در ایران با استفاده از MCDM.دومین کنفرانس علمی مهندسی صنایع

جعفر رزمی . حسن حاله . سعید مشکین فا . طراحی مدل نوین پشتیبانی تصمیم گیری جهت ارزیابی و انتخاب پیمانکاران عمرانی در مناقصه . نشریه دانشکده فنی جلد 41 شماره 7 از صفحه 897 تا 909

پيشينه داخل كشور:

صالحی زاده و فاضل زرندی (1386) در پروژه خود تحت عنوان" مدل تصميم گيري خبره چند معياره فازي براي مطالعات امكان پذيري پروژه هاي تحقيقاتي" ، مدلی خبره تصميم گيري فازي جهت مطالعات امكانپذيري پروژه هاي تحقيقاتي تدوين نموده اند . در اين سيستم پارامترهاي كمي و كيفي مربوط به مطالعات امكانسنجي از كارشناسان و خبره هاي امر و پروژه تحت مطالعه، دريافت شده و در قالب سيستم خبره فازي نوع دوم (fuzzy type II) و مجموعه هاي فازي با ارزش بازه اي (interval valued fuzzy sets) و عملگرهاي فازي پردازش شده و براساس آن قوانيني استخراج و تدوين مي شود تا بتوان بهترين تركيب بهينه را از مقادير پارامترهاي پروژه بدست آورده و در خصوص پارامترهاي فعلي آن و لزوم تغيير موارد لازم تا تصويب و اجراي طرح تصميم گيري شود .

حسن حیدری پور و حسن حسینی نسب (1384) سیستمی تحت عنوان "طراحی سیستم خبره فازی جهت برنامه ریزی استراتژیک" ارائه کردند که: این سیستم در فرایند برنامه ریزی استراتژیک شرکت سنگ آهن مرکزی ایران بکار گرفته شده و توانسته است علاوه بر ارائه لیستی از نقاط قوت و ضعف و فرصت وتهدید، امتیاز سازمان را از نظر عوامل داخلی و خارجی مشخص نموده و با بکارگیری منطق فازی ، استراتژیهای مناسب را جهت سازمان پیشنهاد نماید.

عبدالحمید اشراق نیای جهرمی، محمد دانشور کاخکی (1383) سیستمی تحت عنوان " سیستم خبره فازی لجستیک تیمهای امدادی در بحران پس از وقوع زلزله" طراحی کردند که یک سیستم خبره فازی برای کمک به اتخاذ تصمیمات صحیح در تخصیص تیمهای امداد، تثبیت و پاکسازی میباشد.

پيشينه در خارج ازكشور:

Kuo, Chi, & Kao(2002) has worked a project on " A decision support system for selecting convenience store location through integration of fuzzy AHP and artificial neural network " . This study aims to develop a decision support system for locating a new CVS. The proposed system consists of four components: (1) hierarchical structure development for fuzzy analytic hierarchy process (fuzzy AHP), (2) weights determination, (3) data collection, and (4) decision making. In the first component, the hierarchical structure of fuzzy AHP is formulated by reviewing the related references and interviewing the retailing experts. Then, a questionnaire survey is conducted to determine the weight of each factor in the second component, while the corresponding data are collected through some government publications and actual investigation. Finally, a feedforward neural network with error back-propagation (EBP) learning algorithm is applied to study the relationship between the factors and the store performance. The results show that proposed system is able to provide more accurate result than regression model in accuracy. Recent research has showed that the applications of ANN techniques in decision-making domain are very promising. A feedforward neural network using the golden section search method instead of the traditional steepest descent technique was presented for multiple criteria decision making. The ANN achieved good results in evaluating and ranking alternatives. In addition, the trainability and applicability of ANN techniques to addressing general multi-attribute utility methods problems were also confirmed. In order to evaluate the capability of ANN with error back-propagation learning algorithm in decision analysis, three types of multi-attribute functions: additive, quadratic and Chebyshev were implemented and got excellent solutions for the presented problems.

One of the related approaches using fuzzy sets theory in location selection was proposed by Liang and Wang. In their study, the decision makers use linguistic terms to weigh location factors. Every linguistic term is represented by a triangular fuzzy set so that the fuzzy importance of every location factor can be derived by aggregating the weights from the decision makers. Then, multiplying the fuzzy weights with their respective fuzzy location data and summing them up yield a suitability fuzzy index for each candidate location. According to the suitability indices, the most preferred location can then be targeted. Darzentas(1990) proposed another fuzzy model for facility location problem. His research was to locate a facility constrained by some identified points using fuzzy accessibility measures.

8- مراحل مختلف اجراي طرح پژوهشي (از قبيل مراحل مطالعاتي، آزمايشگاهي ، طراحي نيمه صنعتي و ...)

1) برای این طرح ابتدا نیاز است که یک مطالعه و بررسی جامع در مورد نحوه تصمیم گیری موجود در زمینه انتخاب تامین کنندگان می باشد.

2) شناسایی طیف تامین کنندگان شرکت فولاد مبارکه و شناسایی نکات کلیدی که در انتخاب تامین کنندگان مورد توجه قرار میدهند
3) تجزیه و تحلیل بازاریابی شرکت بر اساس بررسیهای بعمل آمده و تهیه fact وruleهای سیستم
4) طراحی سیستم خبره فازی وارائه به متخصصین بازاریابی جهت تست و اصلاحات مورد نیاز
5) پیاده سازی سیستم خبره
6) ورود اطلاعات پرسشنامه انتخاب تامین کننده به سیستم به شکل فازی
7) تست و نگهداری سیستم تحت نظر متخصصین بازاریابی
8) خطایابی و اصلاح سیستم

9- جدول زماني اجراي مراحل مختلف طرح پژوهشي :

راحل اجراء / طرح / ماه)	1 بررسیها و مطالعات مقدماتی	2 بررسی نیازمندیها	3 تهیه ابزار جمع آوری اطلاعات	4 جمع آوری اطلاعات	5 تجزیه و تحلیل اطلاعات	6 طراحی سیستم	7 پیاده سازی	8 انتقال اطلاعات به سیستم	9 تست و نگهداری	10 خطایابی
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										

10

- هزينه هاي پرسنلي انجام طرح پژوهشي به تفكيك :

رديف	نام و نام خانوادگي مسئوليت در طرح	تخصص	ساعات كار در طرح	حق الزحمه در ساعت (ريال)	حق الزحمه كار (ريال)
1	دکتر عاصفه عاصمی	اطلاع رسانی	600	100000	60000000
2	مهندس عادله عاصمی	هوش مصنوعی	1000	80000	80000000
3	علی علی بیگی	اقتصادی	600	60000	36000000
4	مهندس حسین هوشنگی	نرم افزار	250	40000	10000000
جمع هزينه هاي پرسنلي: (ريال)					186000000
مبلغ بالاسري پرسنلي :					
جمع هزينه هاي بالاسري و پرسنلي :					186000000

11- هزينه هاي مرتبط با تجهيزات و مواد مورد نياز براي اجراي طرح كه لازم است از محل اعتبار اين طرح خريداري شوند .

12- هزينه تستها و آزمايشات (آزمايشگاهي، كارگاهي، نيمه صنعتي)

13- كل هزينه هاي ماموريت ها و مسافرتهاي پيش بيني شده در رابطه با طرح ريال

14- ساير هزينه ها :

15- كل هزينه هاي طرح :

شرح هزينه	كل برآورد مسئول طرح (ريال)	كل مصوب شركت (ريال)
هزينه پرسنلي (بند 10)	186000000	
ماشين آلات و تجهيزات (بند 11-1)	--	
مواد مصرفي (بند 11-2)	--	
مواد مصرف نشدني (بند 11-3)	-	
تست ها و آزمايشات ساخت (بند 12)	-	
مأموريتها و مسافرتها (بند 13)	--	
ساير هزينه ها (بند 14)	--	
بالاسري پرسنلي (بند 10)	--	
بالاسري آزمايشها (بند 12)	-	
جمع كل	186000000	

16 - توجيه فني اقتصادي انجام طرح پژوهشي :

الف - چه واحد يا واحدهائي مستقيماً از نتايج حاصل از انجام طرح استفاده خواهند نمود ؟

این طرح می تواند برای کلیه واحدهایی که نیاز به انتخاب تامین کننده دارند پیاده سازی شود.

ب - توجيه فني : با توجه به موارد بند 6 مسئله را باز كرده و توضيح كافي ارائه نمائيد.

مزاياي سيستم تصميم گيری بر اساس منطق فازی در انتخاب تامین کننده را مي‌توان به صورت زير دسته‌بندي كرد:

1-افزايش قابليت دسترسي: تجربيات بسياري از طريق كامپيوتر دراختيار متخصصين برای انتخاب تامین کننده قرار مي‌گيرد و به طور ساده‌تر مي‌توان گفت يك سيستم خبره،توليد انبوه تجربيات است.

نتیجه:

افزایش کارآیی نیروی انسانی شاغل در شرکت

افزایش دانش فنی و ارتقای تکنولوژی

بهینه سازی سیستمهای تولید و پشتیبانی تولید

2-كاهش‌هزينه:هزينه‌كسب تجربه در زمینه انتخاب تامین کننده براي شركت فولاد مباركه به‌طورزيادي‌كاهش‌مي‌يابد. همچنین نیاز به صرف هزینه جهت تربیت نیروی متخصص و یا استخدام کاهش می یابد.

نتیجه:

کاهش مصرف مواد و انرژی

کاهش هزینه های تولید و نهایتا کاهش قیمت تمام شده

ایجاد سرمایه گذاری بنیادی و ضروری در کشور

3-كاهش خطر: با توجه به سرمایه گذاری های قابل توجهی که در شرکتهای بزرگ صورت میگیرد، درصورتی که تصمیم گیری صحیحی بصورت چند معیاره در بازاریابی اتخاذ نشود منجر به ایجاد ضررهای قابل توجه و در برخی مواردغیر قابل جبران می شود. لذا سیستم خبره تصمیم گیری مي‌تواند در اين جهت نيز بكار رود.

نتیجه:

کاهش میزان خطا در تصمیم گیری و رساندن خطا به حداقل نزدیک به صفر

4-دائمي بودن: سيستمهای فازی در تصمیم گیری دائمي و پايدار هستند. بعبارتي مانندانسان‌ها نمي‌ميرند و فنا ناپذيرند.

نتیجه:

کاهش هزینه های نیروی انسانی

بالا بردن ارزش افزوده

کاهش هزینه های تولید

5-تجربيات چندگانه: اين سيستم مي‌تواند مجموع تجربيات وآگاهي‌هاي چندين فرد خبره باشد كه در امر پیشرفت شرکت همگام با پیشرفت جهانی حرکت کند.

نتیجه:

افزایش دانش فنی و ارتقای تکنولوژی

قطع واردات و کاهش وابستگی

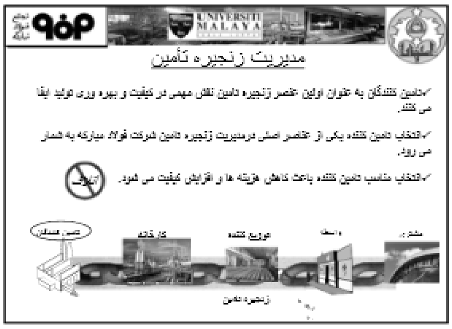
جوابگویی به نیاز بازار

استفاده بهتر از امکانات تولیدی و پشتیبانی تولید
افزایش کارآیی نیروی انسانی شاغل در شرکت
6-افزايش قابليت اطمينان: سيستم‌هاي خبره هيچ وقت خسته وبيمارو بازنشسته نمي‌شوند، و هيچ موقع تحت فشار عوامل خارجی قرار نمی گیرند در صورتی که افراد خبره با چنین مشکلاتی مواجه هستند.
نتیجه:
تثبیت مدیریت و جلوگیری از بی ثباتی
7-قدرت تبيين (Explanation): يك سيستم خبره مي‌تواند مسير و مراحل‌استدلالي منتهي شده به نتيجه‌گيري را تشريح نمايد. اما افراد خبره اغلب‌اوقات بدلايل مختلف (خستگي، عدم تمايل و...) نمي‌توانند اين عمل رادر زمانهاي تصميم‌گيري انجام دهند. اين قابليت، اطمينان شما را در موردصحيح بودن تصميم‌گيري افزايش مي‌دهد.
نتیجه:
کاهش هزینه
بالابردن ارزش افزوده
کاهش هزینه های تولید و قیمت تمام شده
افزایش کارآیی نیروی انسانی
ایجاد سرمایه گذاریهای بنیادی
8-پاسخ‌دهي‌سريع:سيستم‌هاي‌خبره،سريع‌ودراسرع‌وقت‌جواب‌مي‌دهند.
9-پاسخ‌دهي در همه حالات: در مواقع اضطراري و مورد نياز،ممكن است يك فرد خبره بخاطر فشار روحي و يا عوامل ديگر، صحيح‌تصميم‌گيري نكند ولي سيستم خبره اين معايب را ندارد.
نتیجه(8-9):
جلب رضایت مشتری و صرفه جویی در وقت مشتری و مدیر
کاهش هزینه های
جوابگویی به نیاز بازار
10-پايگاه تجربه: سيستم خبره مي‌تواند همانند يك پايگاه تجربه‌عمل كند وانبوهي از تجربيات را در دسترس قرار دهد.
11-آموزش كاربر: سيستم خبره مي‌تواند همانند يك خودآموز هوش(Intelligent Tutor) عمل كند. بدين صورت كه مثالهايي را به سيستم خبره‌مي‌دهند و روش استدلال سيستم را از آن مي‌خواهند.
12-سهولت انتقال دانش: يكي از مهمترين مزاياي سيستم خبره،سهولت انتقال آن به مكان‌هاي جغرافيايي گوناگون است. اين امر براي‌توسعه‌كشورهايي‌كه استطاعت خريد دانش متخصصان‌راندارند،مهم‌است.
ج - توجيه اقتصادي : (اثر اقتصادي حاصل از اجراي نتايج طرح چه ميزان است ؟)

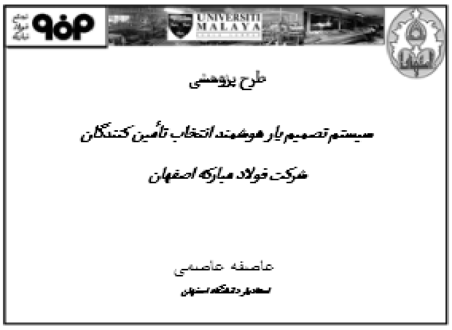
سرعت رشد تحولات صنعتي مي تواند سرنوشت بسياري از طرح هاي مهم صنعتي و توليدي را تحت تاثير قرار دهد. اقتصادي بودن هر طرحي در گرو اجراي موثر آن بر اساس زمان پيش بيني شده و در واقع بررسي هاي دقيق بازار است.

يكي از مشكلات عمده اي كه مديران واحدهاي توليدي، از جمله صنایع تولیدی با آن روبرو هستند مساله انتخاب تامين كننده است. توجه به اين امر که انتخاب تامین کننده تاثیر بسزایی در هزینه ها دارد لذا انتخاب تامين كنندگان مناسب ميتواند سبب ميلياردها تومان صرفه جويي در هزينه هاي پنهان شركتهاي بزرگ چون شركت فولاد مباركه شود.

در این پروژه با ایجاد یک سیستم تصمیم گیری چند معیاره فازی، مديران در امر انتخاب تامين كننده فرصت بهترین نوع تصمیم گیری پیدا می کنند. اين سيستم، با تمركز روي نياز/نظر مديران و با هدف کاهش میزان خطا در تصمیم گیری، ايجاد خواهد شد و همچنين امكان ارتباط با سيستمها و زيرسيستم هاي مرتبط با سيستم انتخاب تامين كننده را فراهم خواهد آورد. پروژه فوق با بکارگیری انواع تكنيكهاي بهينه سازي فازي مي تواند با در نظر گرفتن عدم قطعیت موجود از یک سو و در نظر گرفتن انواع محدوديت هاي حاكم بر سيستم از سوي ديگر، جوابهاي بهينه را در اختيار تصميم گيران قرار دهد. بدين ترتيب با تصمیم گیری صحیح و كاهش هزينه هاي مرتبط با انتخاب تامين كننده، ميتوان سبب صرفه جويي هنگفتی در هزينه هاي شركت فولاد مباركه شد.

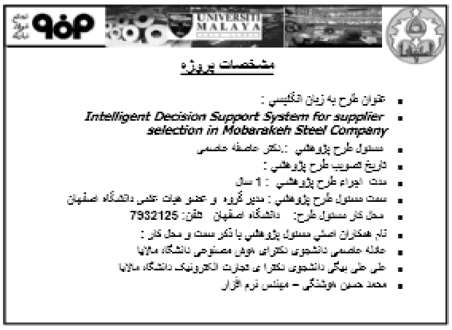


مدیریت زنجیره تأمین
✓تامین کنندگان به عنوان اولین عنصر زنجیره تامین نقش مهمی در کیفیت و بهره وری تولید ایفا می کنند.
✓انتخاب تامین کننده یکی از عناصر اصلی درمدیریت زنجیره تامین شرکت فولاد مبارکه به شمار می رود.
✓انتخاب مناسب تامین کننده باعث کاهش هزینه ها و افزایش کیفیت می شود.
مشتری
واسطه
توزیع کننده
کارخانه
تامین کنندگان
زنجیره تامین

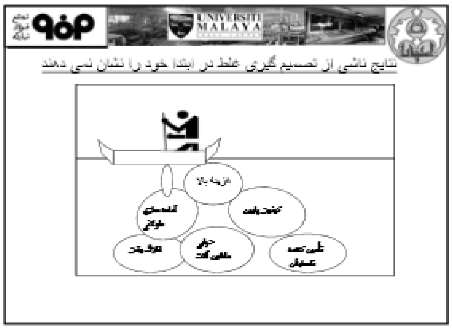


طرح پژوهشی
سیستم تصمیم یار هوشمند انتخاب تأمین کنندگان
شرکت فولاد مبارکه اصفهان
عاصفه عاصمی
استادیار دانشگاه اصفهان

انتخاب تأمین کننده بعنوان یک تصمیم گیری استراتژیک
در عصر جهانی شدن و ارتباطات سازمانها نیازمند اخذ تصمیمات صحیح و سریعند تا بتوانند در عرصه رقابت تنگاتنگ گامی جلوتر باشند.
انتخاب تأمین کننده یکی از مهمترین استراتژی های شرکت ها برای کسب مزیت رقابتی محسوب می شود.
اهمیت استراتژیک این انتخاب بحدی است که تعداد زیادی از پژوهشگران در حوزه هایی چون مهندسی صنایع، مدیریت صنعتی ،مدیریت تولید، اتوماسیون و...حجم زیادی از پژوهش های خود را به موضوع انتخاب تأمین کننده اختصاص داده اند و هر یک مدلهای مختلفی را برای این انتخاب پیشنهاد کرده اند.



مشخصات پروژه
عنوان طرح به زبان انگليسي :
Intelligent Decision Support System for supplier selection in Mobarakeh Steel Company
مسئول طرح پژوهشي :.دكتر عاصفه عاصمي
تاريخ تصويب طرح پژوهشي :
مدت اجراء طرح پژوهشي : 1 سال
سمت مسئول طرح پژوهشي : مدير گروه و عضو هيات علمي دانشگاه اصفهان
محل كار مسئول طرح: دانشگاه اصفهان تلفن: 7932125
نام همكاران اصلي مسئول پژوهشي با ذكر سمت و محل كار :
عادله عاصمی دانشجوی دکترای هوش مصنوعی دانشگاه مالایا
علی علی بیگی دانشجوی دکترا ی تجارت الکترونیک دانشگاه مالایا
محمد حسین هوشنگی – مهندس نرم افزار



نتایج ناشی از تصمیم گیری غلط در ابتدا خود را نشان نمی دهند
هزینه بالا

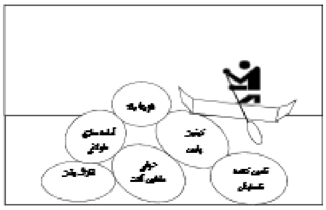
کارهای مشابه

سیستم انتخاب تامین کنندگان کارخانه مکانیک شرکت صنایع الکترواپتیک صا ایران توسط آقای بهرام ایزدی با همکاری شرکت رایان افراز در سال 88 پیاده سازی شده است.

سیستم تصمیم یار جهت امتیاز دهی و رده بندی تامین کنندگان شرکت فولاد تکنیک در سال 89 توسط مهندس نیکتا ناطقی ارایه شده است.

ارایه یک مدل پشتیبان تصمیم گیری جهت برنامه ریزی، ارزیابی و انتخاب تامین کنندگان توسط جعفر رزمی و همکاران سال 82 در نشریه دانشکده فنی تهران به چاپ رسیده است.

با گذشت زمان، مشکلات مشخص می شوند



کارهای مشابه خارجی

Amid, A., S. H. Ghodsypour, et al. (2011). "A weighted max-min model for fuzzy multi-objective supplier selection in a supply chain." International Journal of Production Economics 131(1): 139-145.

Amin, S. H. and J. Razmi (2009). "An integrated fuzzy model for supplier management: A case study of ISP selection and evaluation." Expert Systems with Applications 36(4): 8639-8648.

Amin, S. H., J. Razmi, et al. (2011). "Supplier selection and order allocation based on fuzzy SWOT analysis and fuzzy linear programming." Expert Systems with Applications 38(1): 334-342.

Boran, F. E., S. Genc, et al. (2009). "A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method." Expert Systems with Applications 36(8): 11363-11368.

Chen, C. T., C. T. Lin, et al. (2006). "A fuzzy approach for supplier evaluation and selection in supply chain management." International Journal of Production Economics 102(2): 289-301.

پر رنگ شدن نقش انتخاب تأمین کننده

- یکی از مهمترین دلایل پر رنگ شدن نقش انتخاب تامین کننده برای شرکتها جابجایی پارادایم است.در حالی که در ابتدا شرکتها در پی افزایش فهرست تأمین کنندگانشان بودند تا بتوانند بر سر قیمت ،قدرت چانه زنی خود را افزایش دهند، اینک سعی دارند با تعداد کمتری تأمین کننده که به بهترین نحو نیازهای آنها را برطرف می سازد ارتباط و اتحاد استراتژیک برقرار کنند (جانسون و همکاران 1999).
- این امر از طریق ارتباطی شراکت گونه و تسهیل ارتباطات،تأمین سریعتر و با کیفیت تراقلام بر کارایی واثربخشی شرکت و زنجیره ارزش آن می افزاید.

متدولوژی

این پروژه از چهار فاز تشکیل شده:

فاز اول: تعیین معیارهای انتخاب تامین کننده

فاز دوم: الویت بندی معیارهای

فاز سوم : ارایه متد جدید Multi-Criteria Decision Making(MCDM) تحت محیط فازی

فاز چهارم :درجه بندی تأمین کنندگان

اهداف پروژه

هدف از اجرای این پروژه طراحی و پیاده سازی یک سیستم تصمیم یار هوشمند جهت انتخاب تامین کننده در PFS شرکت فولاد مبارکه می باشد.

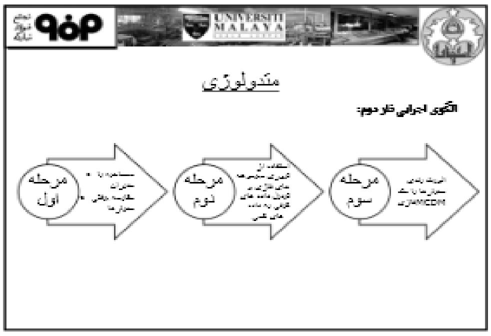
زیر اهداف پروژه عبارتند از:

1.تعیین معیارهای انتخاب تامین کننده در PFS

2. الویت بندی معیارهای تعیین شده

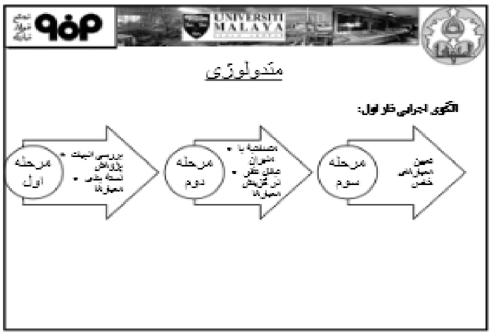
3.ارایه مدل جدید MCDM منطبق با نیازمندیهای PFS

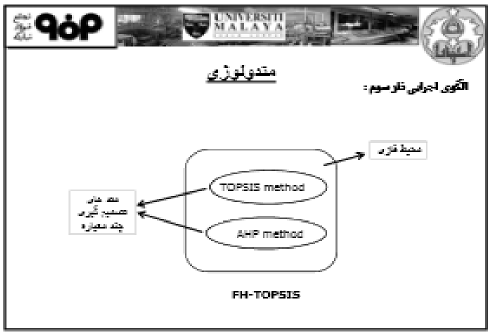
4.رده بندی تامین کنندگان


متدولوژی
الگوی اجرایی فاز دوم:
مرحله اول
مرحله دوم
مرحله سوم


متدولوژی
فاز اول:
تعیین معیارهای انتخاب تامین کننده
این فاز مهمترین فاز اجرای پروژه است که از چندین منبع جهت انجام این قسمت استفاده می شود:
1. مطالعاتی که در زمینه انتخاب تامین کننده انجام گرفته و معیارهایی که به صورت مشترک و عمومی در اکثر آنها بیان شده است.
2. الویت های شرکت در انتخاب تامین کننده و نظرات تصمیم گیران و مدیران موثر در انتخاب تامین کنندم.
3. تعیین معیارها به صورت نهایی


متدولوژی
فاز سوم:
ارایه متد جدید Multi-Criteria Decision Making(MCDM) تحت محیط فازی
این متد جدید FH-TOPSIS نام دارد و بدلیل استفاده از منطق فازی که یکی از تکنیکهای هوش مصنوعی است هوشمند می باشد.
FH-TOPSIS حاصل از ادغام دو متد از کاربردی ترین و مهمترین متدهای MCDM تحت محیط فازی است.
AHP و TOPSIS دو متد بکار رفته در متد جدید می باشند.


متدولوژی
الگوی اجرایی فاز اول:
مرحله اول
مرحله دوم
مرحله سوم


متدولوژی
الگوی اجرایی فاز سوم :
محیط فازی
TOPSIS method
AHP method
FH-TOPSIS


متدولوژی
فاز دوم:
الویت بندی معیارهای
در این فاز در مورد معیار های انتخاب شده درمرحله اول با مدیران تبادل نظر انجام می گیرد
1. تبادل نظر با مدیران در مورد میزان اهمیت هر کدام از معیارها و مقایسه جفتی معیارهاست. خروجی این قسمت نظرات مدیران به صورت متغیرهای زبانی و کیفی است.
2. استفاده از تکنیک های هوش مصنوعی برای تبدیل متغیرهای زبانی به داده های کمی بدینوسیله دانش مدیران شبیه سازی شده و سیستم هوشمند می شود.
3. الویت بندی معیارها